

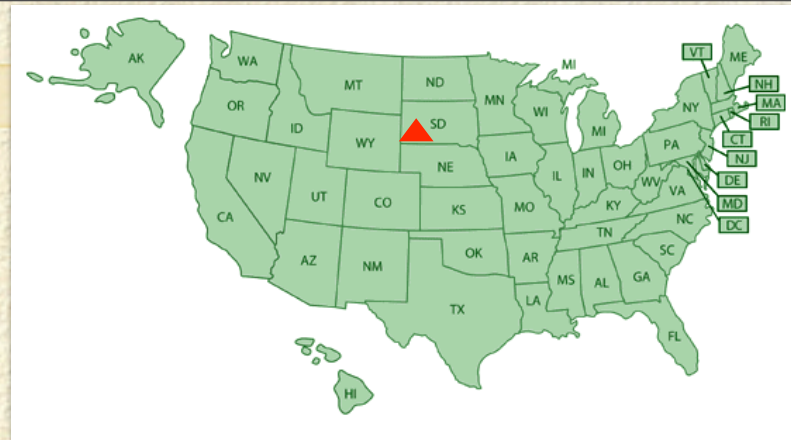
Deep Underground Science and Engineering Laboratory at Homestake

Kevin T. Lesko

UC Berkeley and Lawrence Berkeley National Laboratory

4 March 2008





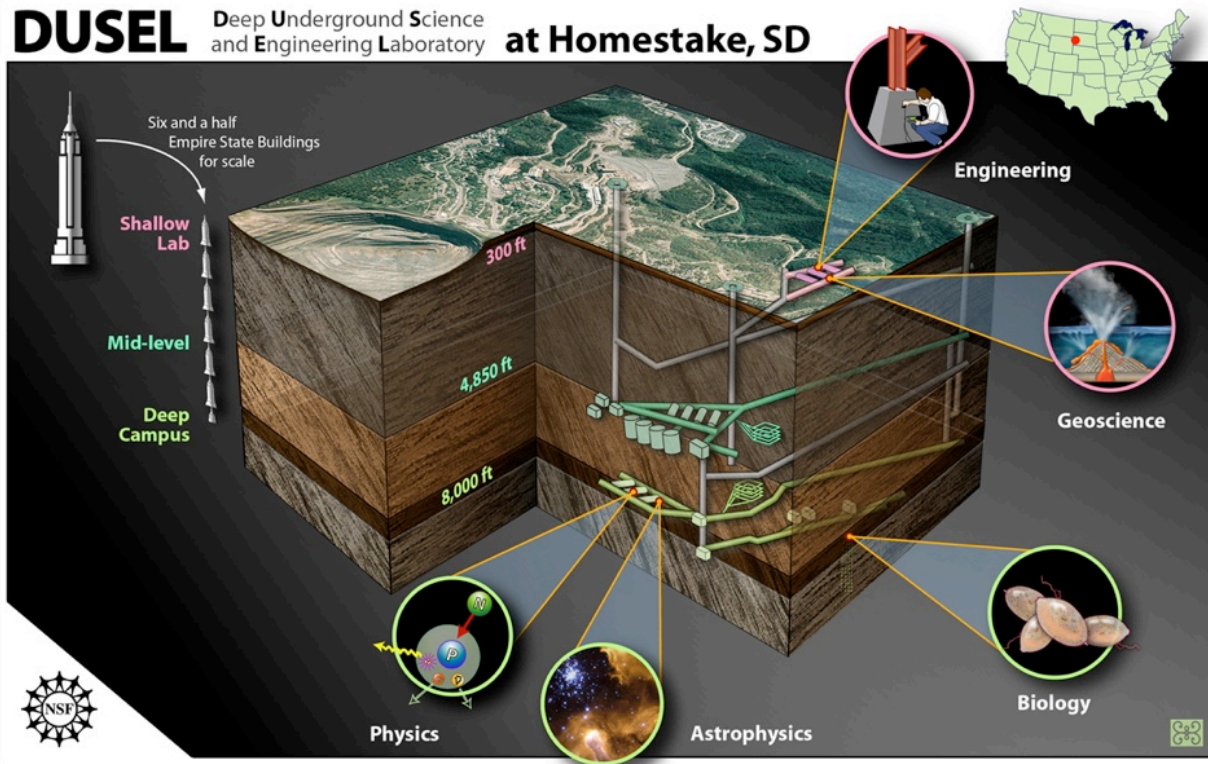
Deep Underground Science and Engineering Laboratory at Homestake

Kevin T. Lesko

UC Berkeley and Lawrence Berkeley National Laboratory

4 March 2008





1. Progress in Establishing NSF's Deep Underground Science and Engineering Laboratory (DUSEL)
2. Independent Assessment DUSEL's Science Goals (Deep Science)
3. Progress in establishing DUSEL at Homestake and the Sanford Laboratory's Early Options for Science

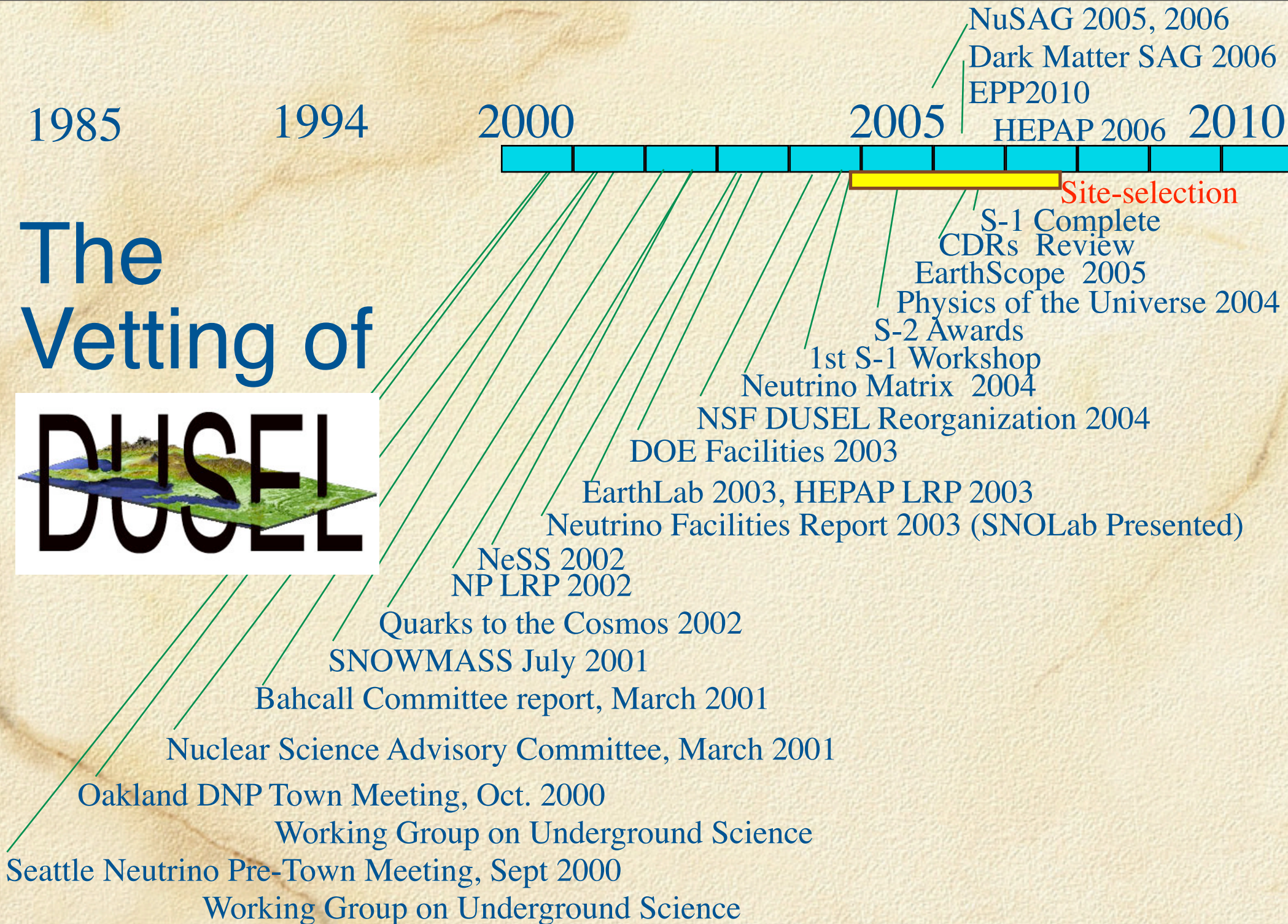
Nomenclature

- Sanford Lab - *noun* - surface to 4850L, mostly in the Davis Cavity (\$65M State-run project), sometimes referred to as SUSEL
- Sanford Lab hosts Early Implementation Program - 12 experiments between 2007 and 2011 (starting point for DUSEL construction)
- DUSEL - *noun*, - NSF process to establish an MREFC and create a major new user facility (\$500M total = \$250M facility, \$250M expts.)

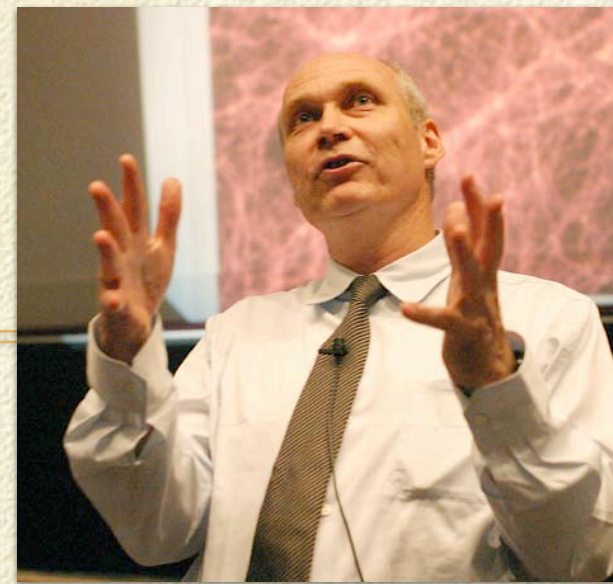
Nomenclature

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- Sanford Lab hosts Early Implementation Program ~ 12 experiments between 2007 and 2011 (starting point for DUSEL construction)
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The Vetting of



NSF DUSEL Process: March 2004



□ NSF's DUSEL-Process Defined

- ☑ S-1: site-independent science case for DUSEL
 - ☑ Sadoulet led this effort
- ☑ S-2: site dependent projection on different sites (Conceptual Design Report) 8 applications
 - ☑ Homestake and Henderson received awards
- ☑ S-3: Technical Design solicitation *competition*
 - Funding in *FY11* DUSEL construction

DUSEL Progress



- ☑ S-1 Awarded to Bernard Sadoulet, UC Berkeley with Hamish Robertson, U.W.; Gene Beier, U. Penn; Charles Fairhurst, U. Minnesota; T.C. Onstott, Princeton; James Tiedje, Michigan State
- ☑ Conducted extensive workshops, information gathering, discussions with the agencies, foreign laboratories, etc.
- ☑ S-1 Report Released: www.dusel.org - [Deep Science](#)
- ☑ S-2 8 Candidate sites, 2 awards
- ☑ July 2006 Henderson and Homestake

Time Table

- ☑ **August 06** anonymous review of CDRs
- ☑ **September 06** S-3 solicitation announced, to develop Preliminary Design
- ☑ **Fall 06** NSF and DOE announce call for proposals for DUSEL R&D
- ☑ **9-13 March 07** sites visits as part of review
- ☑ **19-22 April 07** review of proposal teams in DC
- ☑ **10 July 07** Site Selection of Homestake



Time Table *continued*

- **Winter 07** Call for **Initial Suite Experiments** by NSF
 - 2-4 November Town Meeting 1st step in defining ISE
 - Next step for the facility is to baselined DUSEL plan, to be prepare for review by NSF, NSB, ..., Final Design
 - Collaboration is open and welcomes participation
- **FY12 DUSEL funding**, include Experiments and Facility
 - Experiments to be 1/2 of the ~\$500M MRE proposal
- Normal R&D, Proposal and DOE “on ramps,” as well for experiments, research, and activities at the site

S-I Findings & Recommendations



Findings:

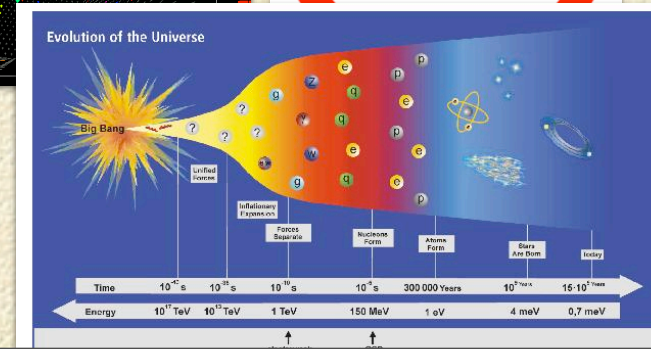
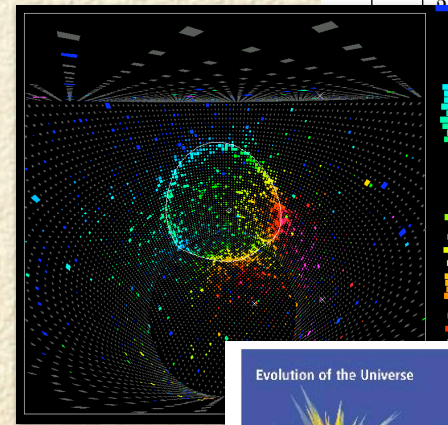
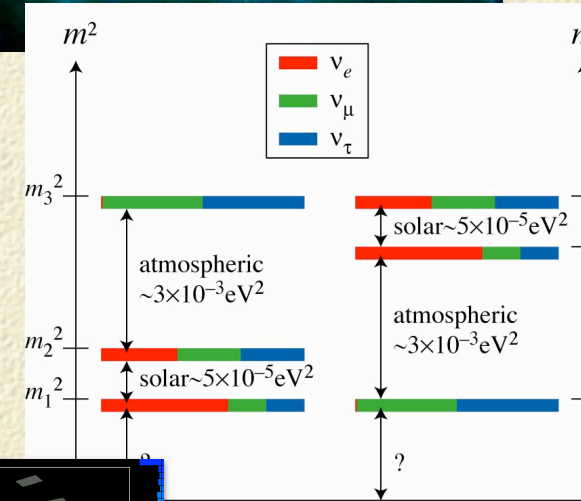
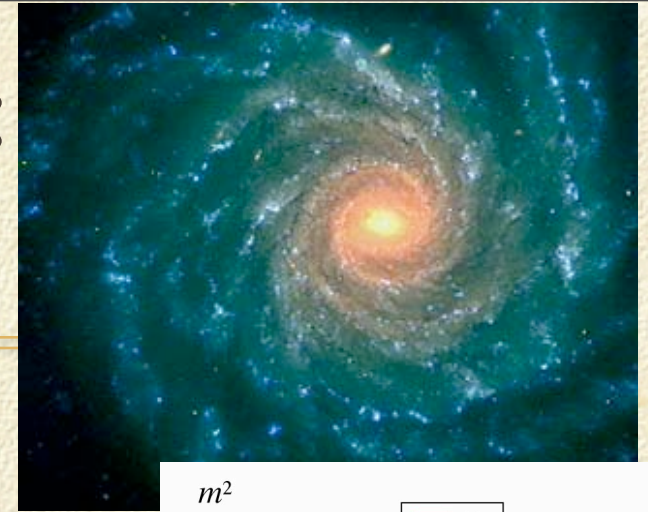
- Deep underground science is an essential component of research at the frontier
 - Disciplines in transformation
- Benefits to society
 - Worldwide need for underground space
- Need for a U.S. world-class deep multidisciplinary facility
- Recommendations:
 - Strong support for deep underground science
 - A cross agency Deep Science Initiative
 - A Deep Underground Science and Engineering Laboratory (6000 mwe, 3000 mwe, 30 to 50 years, ASAP)

www.dusel.org

Deep Science

Deep Science Questions: Physics & Astrophysics

- What is the universe made of?
- What is dark matter?
- What are neutrinos telling us?
- What happened to the antimatter?
- Are protons unstable?
- How did the universe evolve?



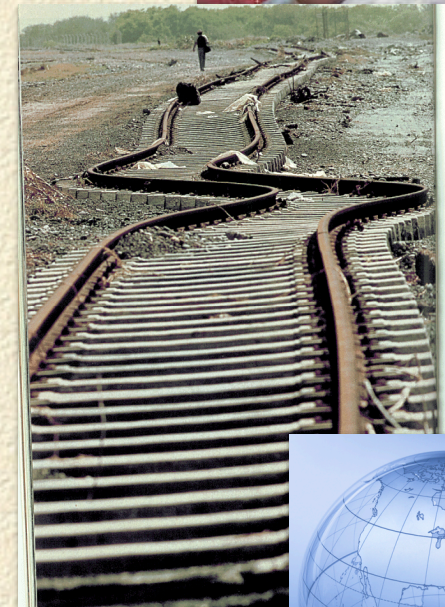
Deep Science Questions: Geology & Biology

- How do biology and geology interact to shape the world underground?
- How does subsurface microbial life evolve in isolation?
- Did life on earth originate beneath the surface?
- Is there life underground as we don't know it?



Deep Science Questions: Geology

- What are the interactions among subsurface processes?
- Are underground resources of drinking water safe and secure?
- Can we reliably predict and control earthquakes?
- Can we make the earth “transparent” and observe underground processes in action?



Deep Science Questions: Geology and Engineering

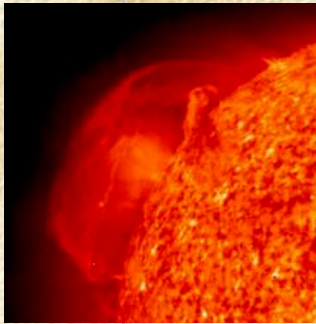
- What are the mechanical properties of rock?
- What lies between the boreholes?
- How does rock respond to human activity?
- How does water flow deep underground?
- How can technology lead to a safer underground?



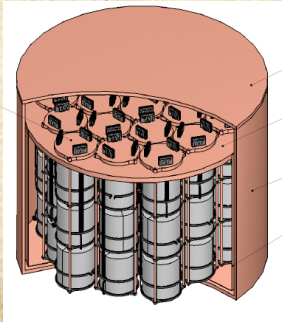
Homestake DUSEL: Multidisciplinary User Facility



Physics
Dark Matter
Cosmology
Astrophysics
Neutron Oscillation



Solar Neutrinos
Geoneutrinos
Underground
Accelerator for
Astrophysics
Gravity Waves

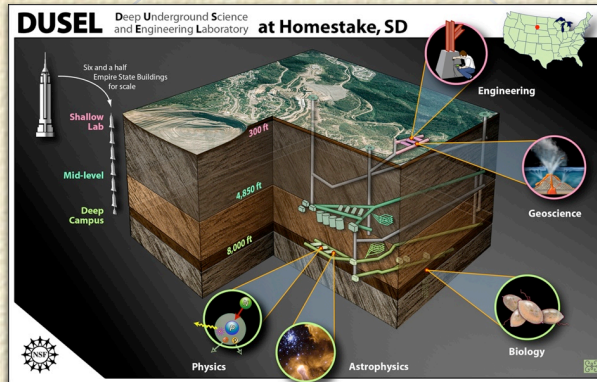


Neutrinoless $\beta\beta$ Decay
U/G Manufacturing
Low Background Counting

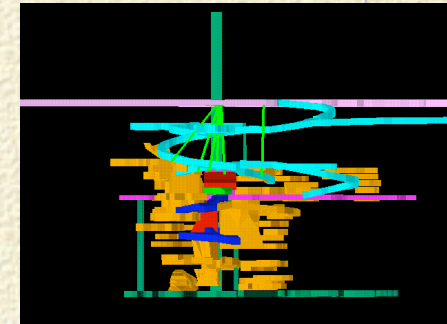


Neutrino Properties
Long-baseline ν Oscillation
CP violation
MNSP Matrix
Nucleon Decay
Atmospheric Neutrinos

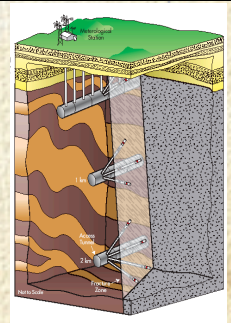
Education & Public Outreach



Earth Science
Geo-Database
Geo Modeling
Geophysics
Seismology
Fracture Study



Cloud Formation
Lightning Physics
Thermal History

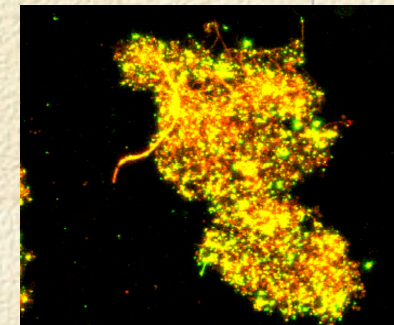


Coupled Processes
Rock Mechanics
Hydrology

Mineral Studies
Economic Geology



Geomicrobiology
Bioprospecting
Life at Extreme
Conditions



Underground Engineering

Geochemistry
Ecology
Environmental
Studies

Homeland Security

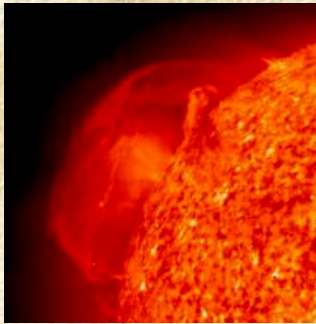
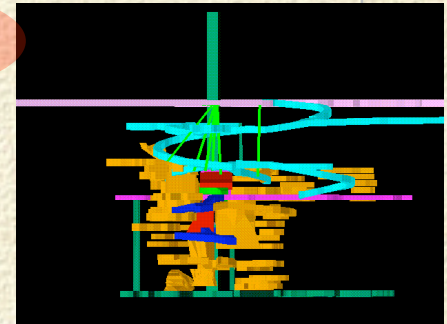
Homestake DUSEL: Multidisciplinary User Facility



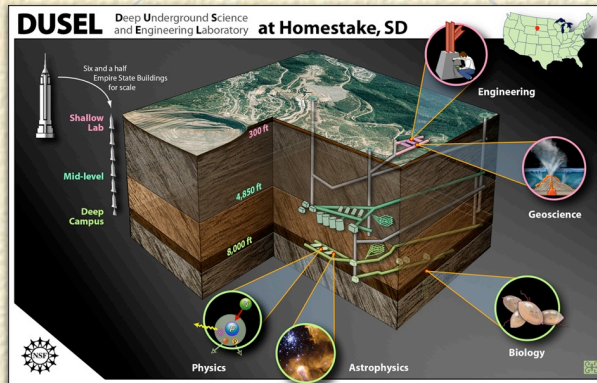
Physics
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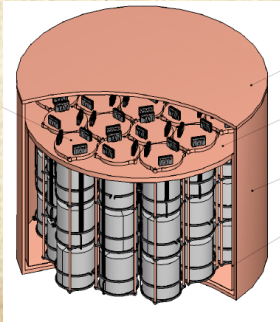
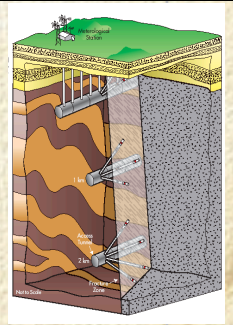
Solar Neutrinos
Geoneutrinos
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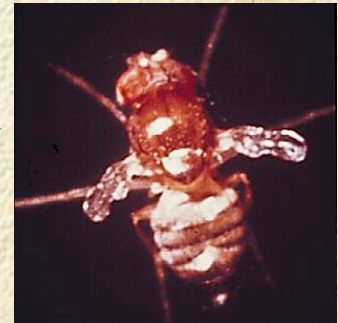
Coupled Processes
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Neutrinoless $\beta\beta$ Decay
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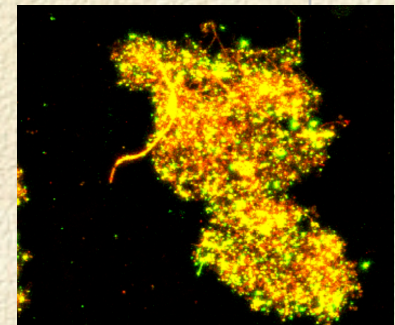


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Studies

Homeland Security



DUSEL Initial Suite of Experiments (ISE)¹

Experimental
Cavity Size
(m²)^{2a}

Required
U/G
Support
Space
(m²)^{2b}

Minimum
Depth
(mwe)³

Approximate
Construction Start
Date for
"Generations" or
Experiments⁴

Dark Matter (WIMPS)

Generation 0 (PreDUSEL) Sensitivity 10 ⁻⁴⁴ - 10 ⁻⁴⁵				
Noble Liquid (2 phase)	100	250	4100	LUX 300 proposal for Sanford Lab (2008) (Xe)
Low Temperature Solid State	100	250	2000	CDMS Experiment in Soudan (running) (Ge + Si)
Low Temperature Solid State	100	250	4100	SuperCDMS Proposal to SNOLab (2009) (Ge + Si)
Noble Liquid (1 phase)	N/A	N/A	N/A	miniClean Proposal to SNOLab (2008) (Ar)
Noble Liquid (2 phase)	N/A	N/A	N/A	WARP Experiment to Gran Sasso (running) (Ar)
Noble Liquid (2 phase)	N/A	N/A	N/A	Xenon10 Experiment to Gran Sasso (completed) (Xe)
Noble Liquid (2 phase)	N/A	N/A	N/A	Xenon100 Proposal to Gran Sasso (2008) (Xe)

Generation 1 (DUSEL ISE) Sensitivity 10 ⁻⁴⁵ - 10 ⁻⁴⁶				
Technology 1 TBD	100	250	4100	~ 2011 - 2013 detector construction to commence earlier on the surface
Technology 2 TBD	100	250	4100	detector construction to commence earlier on the surface
Generation 2 (DUSEL ISE) Sensitivity 10 ⁻⁴⁶ - 10 ⁻⁴⁷				
Technology 1 TBD	200	500	6400	~ 2015 detector construction to commence earlier on the surface
Technology 2 TBD	200	500	6400	detector construction to commence earlier on the surface

Neutrinoless Double Beta Decay

Generation 0 (PreDUSEL) Degenerate Mass Scale Sensitivity				
Solid State (Ge)	100	200	4100	R&D for demonstrator prior to MREFC at Sanford Lab (2009)
Noble Liquid (Xe)	150	200	2000	EXO200 running at WIPP Cuoricino running, Cuore being built at Gran Sasso (2010)
Bolometric (Te European)	N/A	N/A	3200	
Generation 1 (DUSEL ISE) Atmospheric Mass Scale Sensitivity				
Solid State (Ge)	250	500	6400	~ 2015
Noble Liquid/Gas (Xe)	500	200	6400	

Dark
Matter

Concepts for
Initial Suite of
Experiments, to
be revised with
community
based program

Neutrinoless
Double Beta
Decay

DUSEL Initial Suite of Experiments (ISE)¹

Experimental
Cavity Size
(m²)^{2a}

Required
U/G
Support
Space
(m²)^{2b}

Minimum
Depth
(mwe)³

Approximate
Construction Start
Date for
"Generations" or
Experiments⁴

Long Baseline Neutrinos and Nucleon Decay

Large Cavity R&D (~ 100kt first cavity)	2400	250	4100	
Site Investigations, coring, geotech work				~ 2008 - 2009
Continued geotech work, and Initial mobilization, instrumentation, access drifts				~ 2011
1-time equipment costs				
Excavation ~ 55m cavity				~ 2012
				~ 2015
Instrumentation				(PMT production to start earlier)
1 Ton Liquid Argon Module at 300 Level	500	200	230	~2013

Nuclear Astrophysics

Low Energy Accelerator	800	200	4100	~ 2013
Heavy Ion Medium Energy Accelerator				~ 2015

Geoneutrino (multipurpose)

1 kt liquid Scintillator Detector	250	250	4100	~ 2015
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Low Energy Solar Neutrinos

Generation 0 (PreDUSEL) (7Be, CNO?, pep?)

Borexino	1000		3700	Borexino running at Gran Sasso
KamLAND	300	200	2000	Kamland Solar being developed in Kamioka
miniLENS	100	100	4100	miniLENS stage II proposal for Sanford Lab (2009)

Generation 1 (DUSEL) (pep, pp)

Charged Current (CC)	250	200	4100	~ 2013
1 kt liquid Scintillator Detector (ES)	250	250	4100	~ 2015
3000kg Noble Gas (ES)	500	200	6400	~ 2015

Characterization of Low Vibration Studies for Future Gravity Wave Experiments

Low vibration and microseismic studies	20000		1690	~ 2013
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Long Baseline
Neutrinos +
Nucleon Decay

Nuclear
Astrophysics
Geoneutrinos

Low Energy Solar
Neutrinos

Gravity Waves

DUSEL Initial Suite of Experiments (ISE) ¹	Experimental Cavity Size (m ^{^2}) ^{2a}	Required U/G Support Space (m ^{^2}) ^{2b}	Minimum Depth (mwe) ³	Approximate Construction Start Date for "Generations" or Experiments ⁴
GeoBiology				
Biology Observatory	50	200	6400	~ 2014
Pristine Fracture Zone		300	6400	~ 2016
Intermediate Bio/Geo Drilling	50	300	4100	~ 2011
Deep Bio/Geo Drilling	50	300	7000	~ 2015
Deep Engineering and Excavation Research Facility				
Cavity Engineering	200	100	4100	~ 2011
Excavation Research (TBM)	400	200		
Excavation Research (Drilling)	200	100		
Cavity Engineering	200	100	6400	~ 2016
Excavation Research (TBM)	400	200		
Excavation Research (Drilling)	200	100		
Scale Effects Experiment				
Run-of-Mine Fracture Characterization	50	50	4100	~ 2011
State-of-Stress and Deformation Research	50	50		
Multiphase Fluid Flow Research	50	50		
Run-of-Mine Fracture Characterization	50	50	6400	~ 2016
State-of-Stress and Deformation Research	50	50		
Multiphase Fluid Flow Research	50	50		
Seismic Array - surface	1000		100	~ 2008
Seismic Array - 3800	1000	10	3200	~ 2009
Active Processes Laboratory				
Transparent Earth (Shallow)		200	4100	~ 2011
Transparent Earth (Deep)	200	100		
THMBC (Chemical Migration)	200	100		
THMCB (Multiphase Migration)	200	100		
Fracture Processes Facility	1000	200		
Transparent Earth (Deep)	200	100	6400	~ 2016
THMBC (Chemical Migration)	200	100		
THMCB (Multiphase Migration)	200	100		
Fracture Processes Facility	1000	200		
CO2 Sequestration and Flow	bore holes		Various	~ 2011
Low Background Counting				
Prescreening array, ICPMS & NAA Assay Facility	50	100	230	~ 2011
Gamma, Beta, Alpha, Whole Body Assays and Radon Emanation Measurements	200	100	4100	~ 2011
Materials Storage				
	150		230	~ 2013
	150		4100	~ 2011
	150		6400	~ 2013
Ultralow Background Materials Processing				
Copper Facilities including Ultraclean Machine Shop	350	150	4100	~ 2011
Education and Outreach				
Shallow Lab	250	100	230	~ 2013
Intermediate Depth Lab	100	100	4100	~ 2013
Prototyping and R&D				
	500	500	230	~ 2013
	250	500	4100	~ 2015
	250	500	6400	~ 2017

Geobiology

Engineering and Excavation
Research

Scale Effects

Active Processes

Low Background Materials

Education and Outreach

Homestake DUSEL Plans

300L R&D, E&O

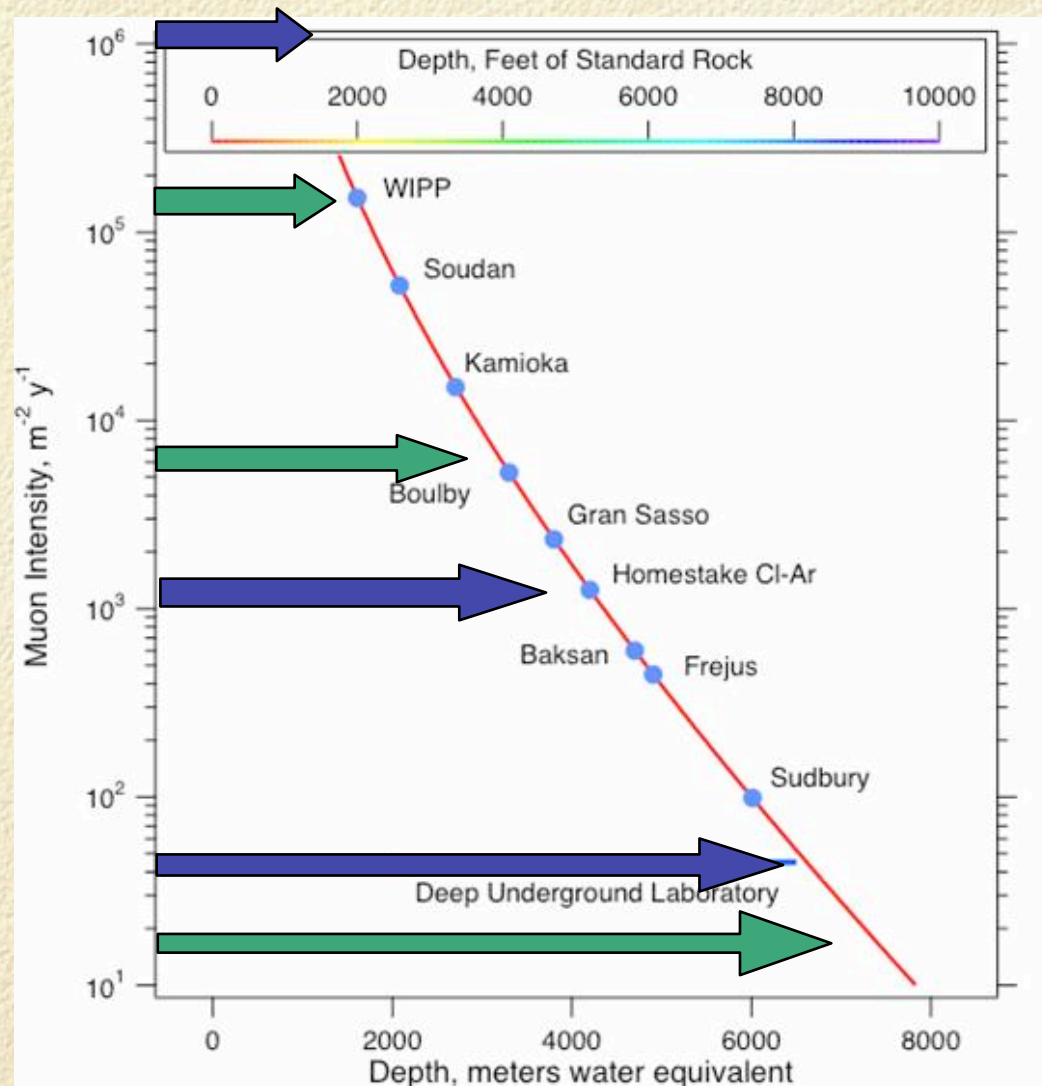
2000L Geo Level

3800L Geo Level

4850L Major Campus

7400L Major Campus

8000L Geo Lab

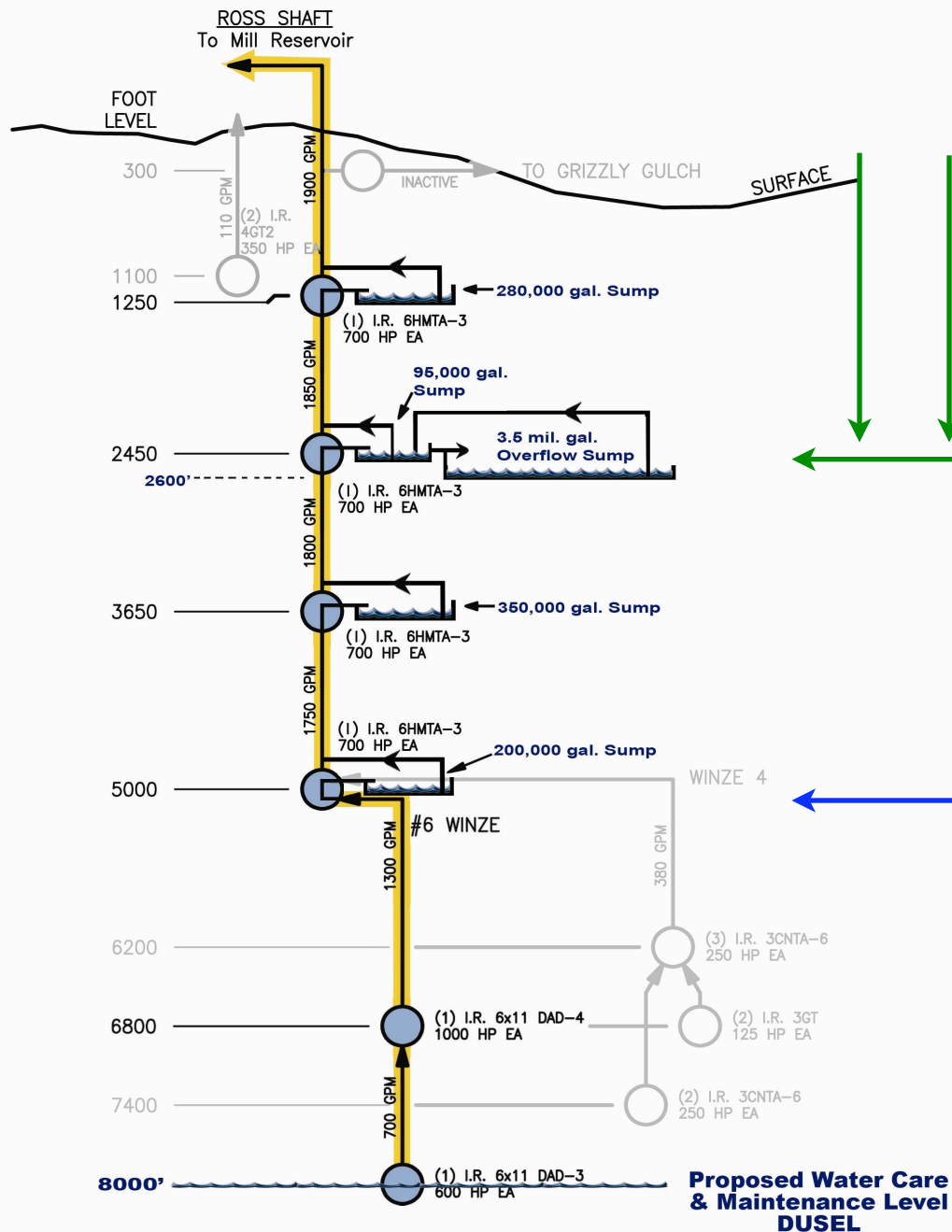


Progress at Sanford Lab

- ✓ October 2005, State Legislature approves additional \$20M funding for Homestake, total of \$46M
- ✓ 1 November 2005 - First call for Letters of Interest for Homestake - 85 letters received
- ✓ Property Donation Agreement Completed 14 April 2006, Property transferred May 2006, SDSTA hiring staff to oversee and operate Homestake: ~30 for rehabilitation, ~25 to 30 staff members
- ✓ January 2007 Rehab work initiated
- ✓ October 2007 SDSTA Hire Jose Alonso, Lab Director
- Early Implementation Program at Homestake 2008 - 2012 "The Sanford Laboratory"



Ross Pumping Diagram

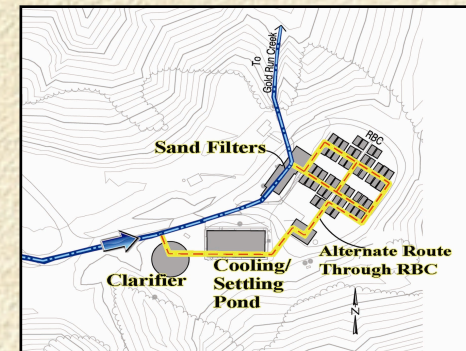


Dewatering Homestake

Current Water Levels

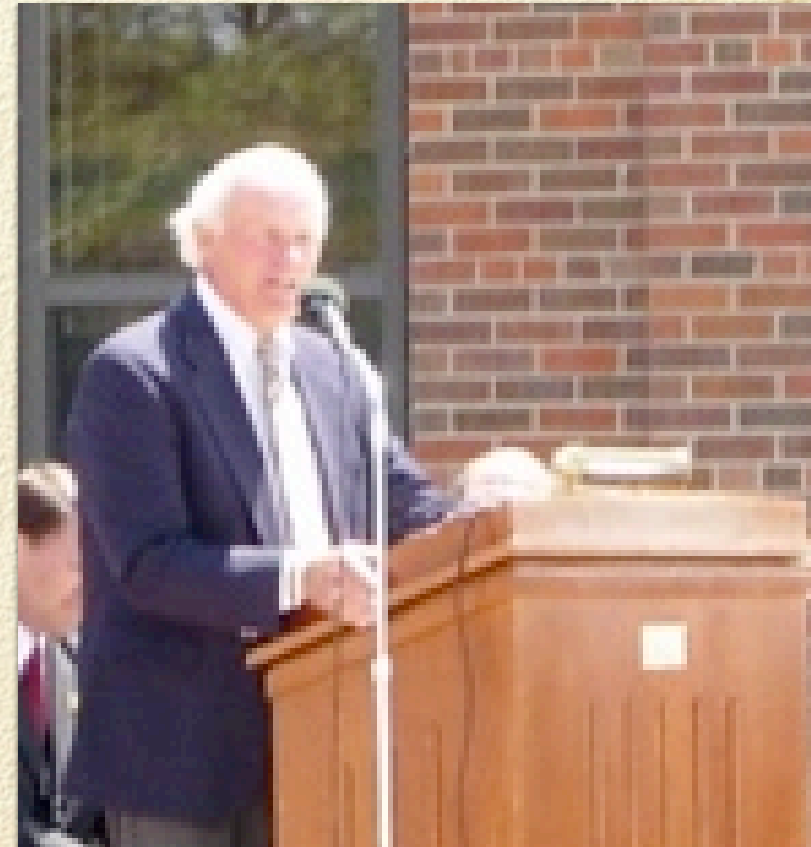
Re-entry Efforts, begun in July, have inspected levels and shafts down to 2450 L. Will focus on turning on pumps at 1250L and 2450L this winter.

5000 level tripped July 2007 (6 weeks earlier than original model)



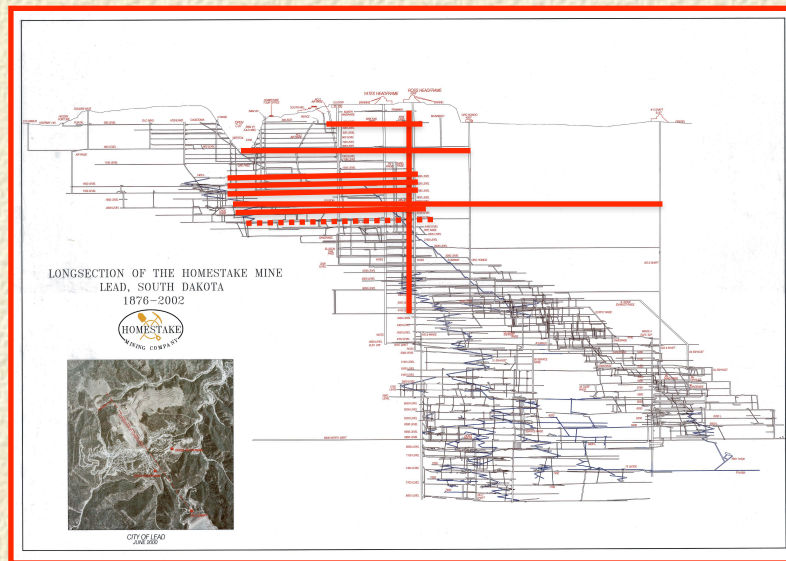
Progress at Homestake

- ☑ June 2006 announced Sanford Gift to Homestake, **\$70M** to establish the laboratory, provide infrastructure, facility improvements
- T. Denny Sanford, banker and financier, operations of credit card and bank from S.D.
- History of donations to hospitals, universities, educational and children's causes



Re-entering Homestake and establishing the Sanford Laboratory

- Shaft Inspections and Maintenance (Ross then Yates)
- Level Inspections
- Pumping
- Ventilation
- Early Implementation Program at Homestake's Sanford Laboratory



1250 Level July 2007
First Pump Station ready
for Operation



Re-entry Timeline

SDSTA plan for installation of
Ross Shaft Pumping System to
hold the accumulated water below
the 5300 L

Recently rehabilitated down to
the 2450 L

Initial Science Program Initiated: geology,
hydrology, biological sampling taking
place with re-entry



Sanford Lab Science Program: 2007 - 2010

Dark Matter: Gaitskell, Shutt and collaboration

Geo/seismic array: Glaser, Johnson, Roggenthen

Low Background Counting: Mei and collaboration

~~Dark Matter: Hime, McKinsey~~ Declined

Dark Matter: Mei and collaboration

Geo/Bio Sampling: Bang, Conrad & collaboration

Neutrinoless $\beta\beta$: Elliott, Wilkerson & collaboration

Large Cavities, LBL vs: Lande, Diwan et al.

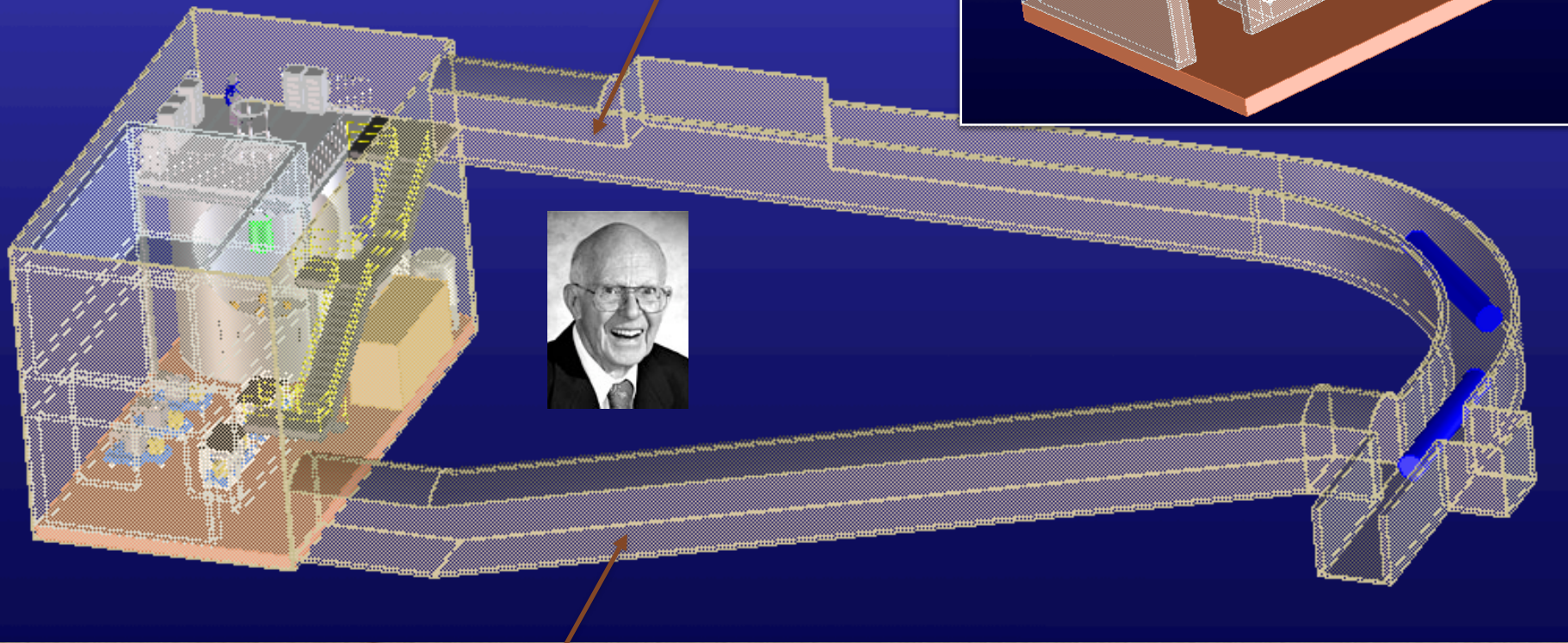
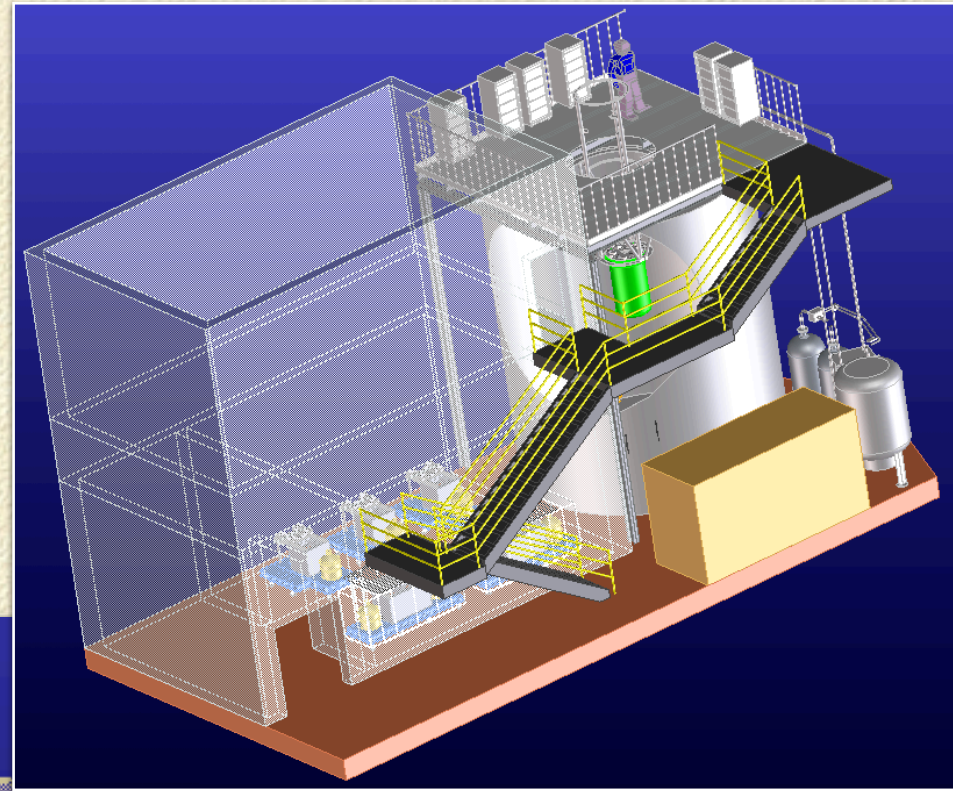
Carbon Sequestration: Wang and collaboration

USGS Gravity Line: Anderson and collaboration

Dark Matter Experiment with Low Background Facility

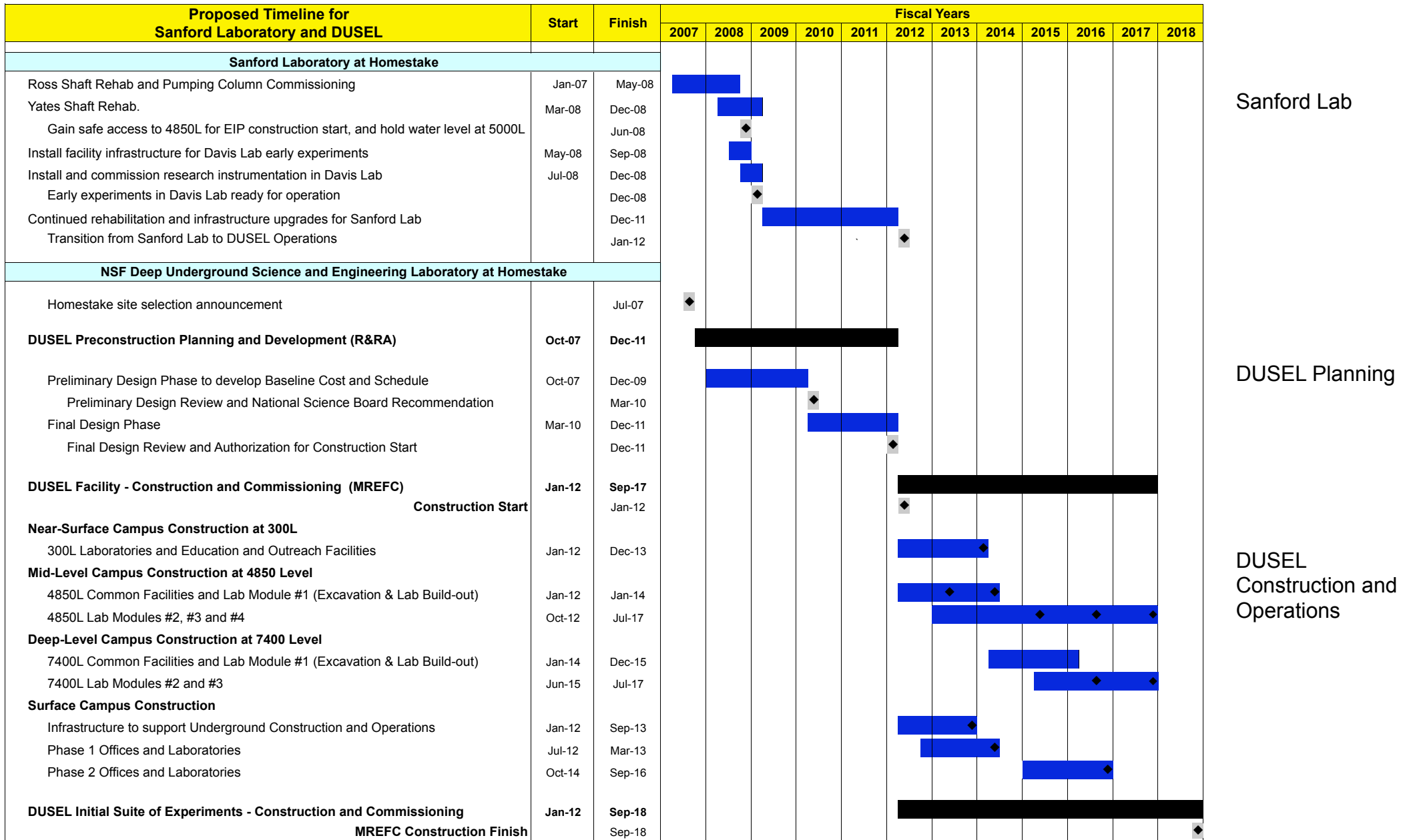
Current Davis Cavity
Dimensions:
55ft x 30ft x 32ft high

4850L
Access

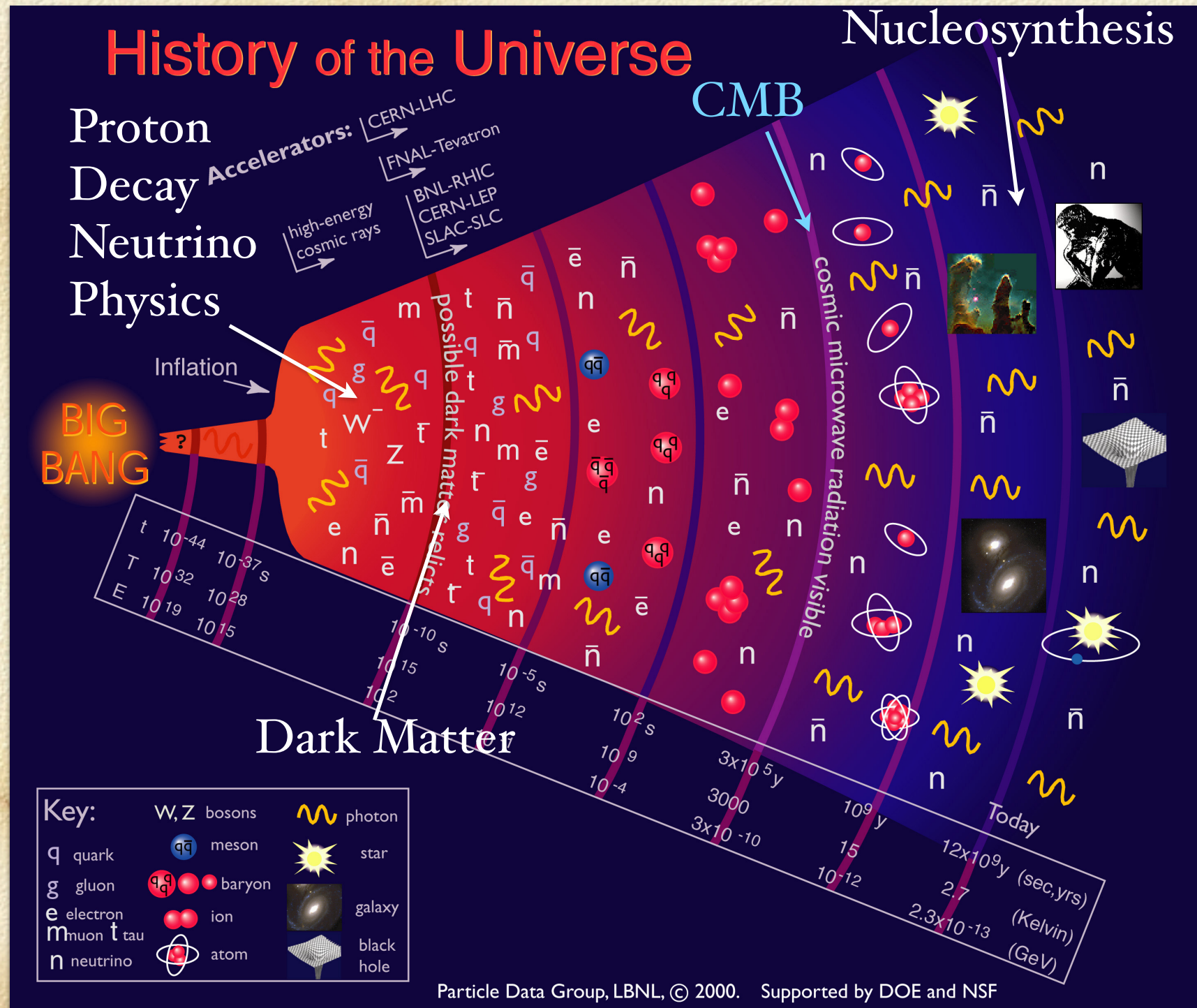


4850L Secondary Access

Milestone Schedule



Underground Physics: Studying the Early Universe



Homestake PIs, Senior Personnel & Coordinators

- ❑ Michael Barnett, LBNL (E+O)
- ❑ Yuen-dat Chan, LBNL (Other uses)
- ❑ Milind Diwan, BNL (lbl, pdk)
- ❑ Reyco Henning, UNC (ovdbd, dm)
- ❑ Ken Lande, Penn (lbl, pdk, geo-neutrinos)
- ❑ Bob Lanou, Brown (neutrinos, solar neutrinos)
- ❑ Chris Laughton, FNAL (engineering)
- ❑ Kevin T. Lesko, UCB (physics) PI
- ❑ Stu Loken, LBNL (E+O)
- ❑ Hitoshi Murayama, UCB (physics theory, neutrinos)
- ❑ Tommy Phelps, ORNL (geomicro)
- ❑ Bill Roggenthen, SDSM&T (geophysics) coPI
- ❑ Ben Saylor, BHSU (E+O)
- ❑ Tom Shutt, Case Western (low backgrounds)
- ❑ Nikolai Tolich, UW (geonus)
- ❑ Bruce Vogelaar, Virginia Tech (solar nus)
- ❑ Herb Wang, U Wisc. (geology, rock mechanics)
- ❑ Joe Wang, LBNL (earth science, geophysics)

Richard DiGennaro, LBNL, Project
Manager and Systems Engineer

Dianna Jacobs, LBNL Project Controls

Liz Exter, Dave Plate, Project
Engineering

Mark Laurenti, Mining Engineer

Syd DeVries, Mining Engineer

Dave Snyder, SDSTA Exec. Director

Trudy Severson, SDSTA

SDSTA Engineering and Safety Personnel

Ms. Melissa Barclay & Cathy Thompson

<http://www.lbl.gov/nsd/homestake>

<http://neutrino.lbl.gov/Homestake/LOI>

<http://neutrino.lbl.gov/Homestake/FebWS>

<http://homestake.sdsmt.edu/HRB/Refer.htm>

<http://neutrino.lbl.gov/Homestake>

<http://www.dusel.org>



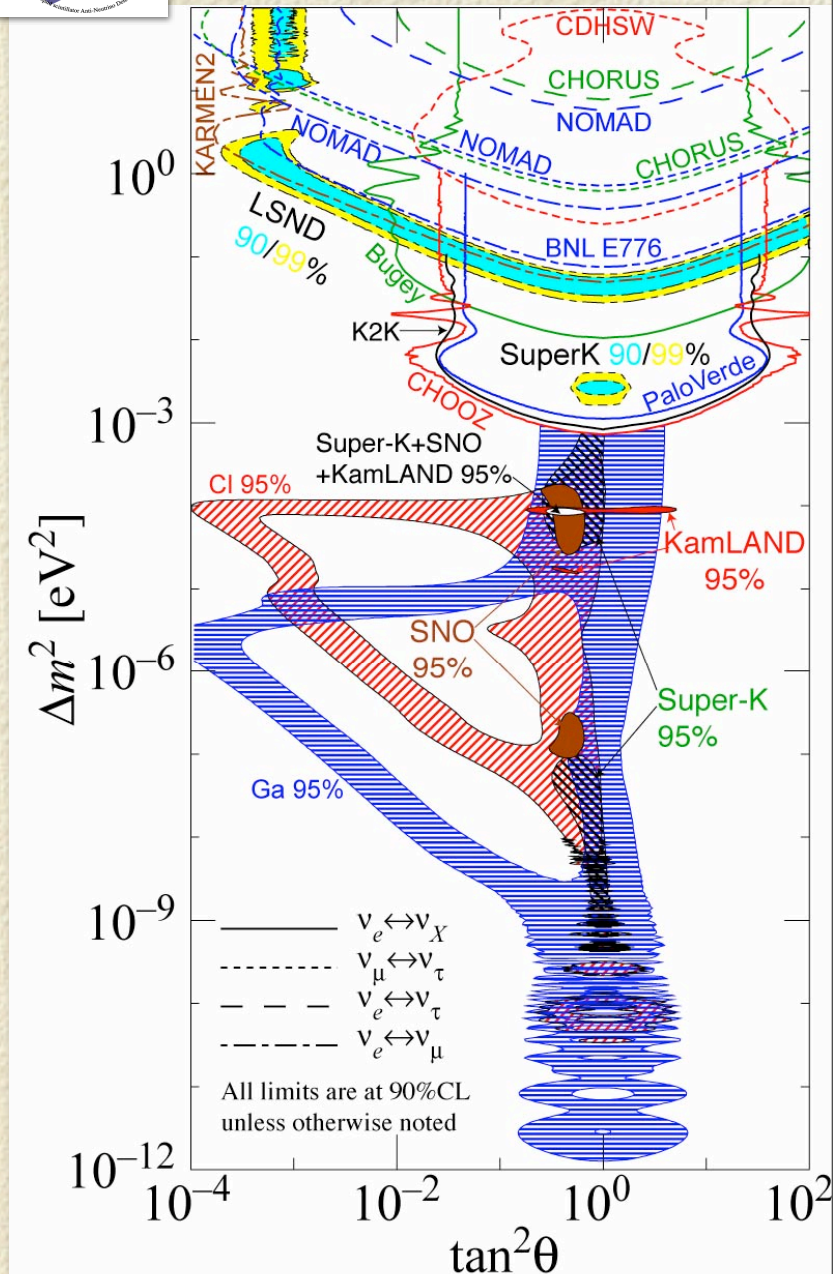
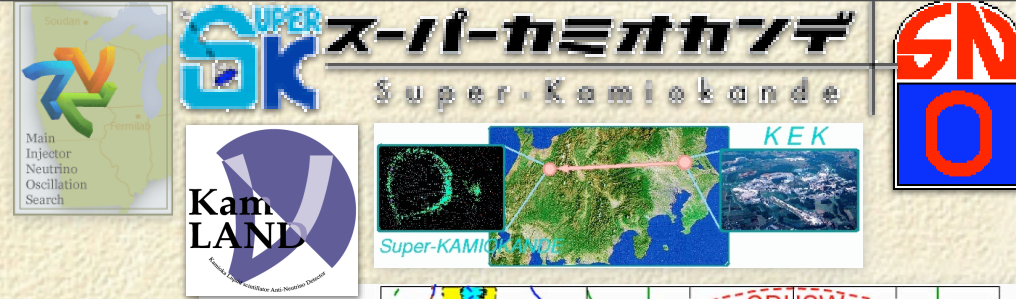
back up slides

Physics Motivations for DUSEL: Neutrinos

- We know neutrinos have mass and have a relative scale, but don't know the absolute mass scale
- We know neutrinos mix and oscillate between the three families but don't know all the mixing parameters
- We don't know if neutrinos are their own anti-particles
- We don't know if neutrino oscillations violate CP conservation
- We don't know if there are only 3 families of neutrinos
- Neutrinos have surprised us every time for the past 80 years

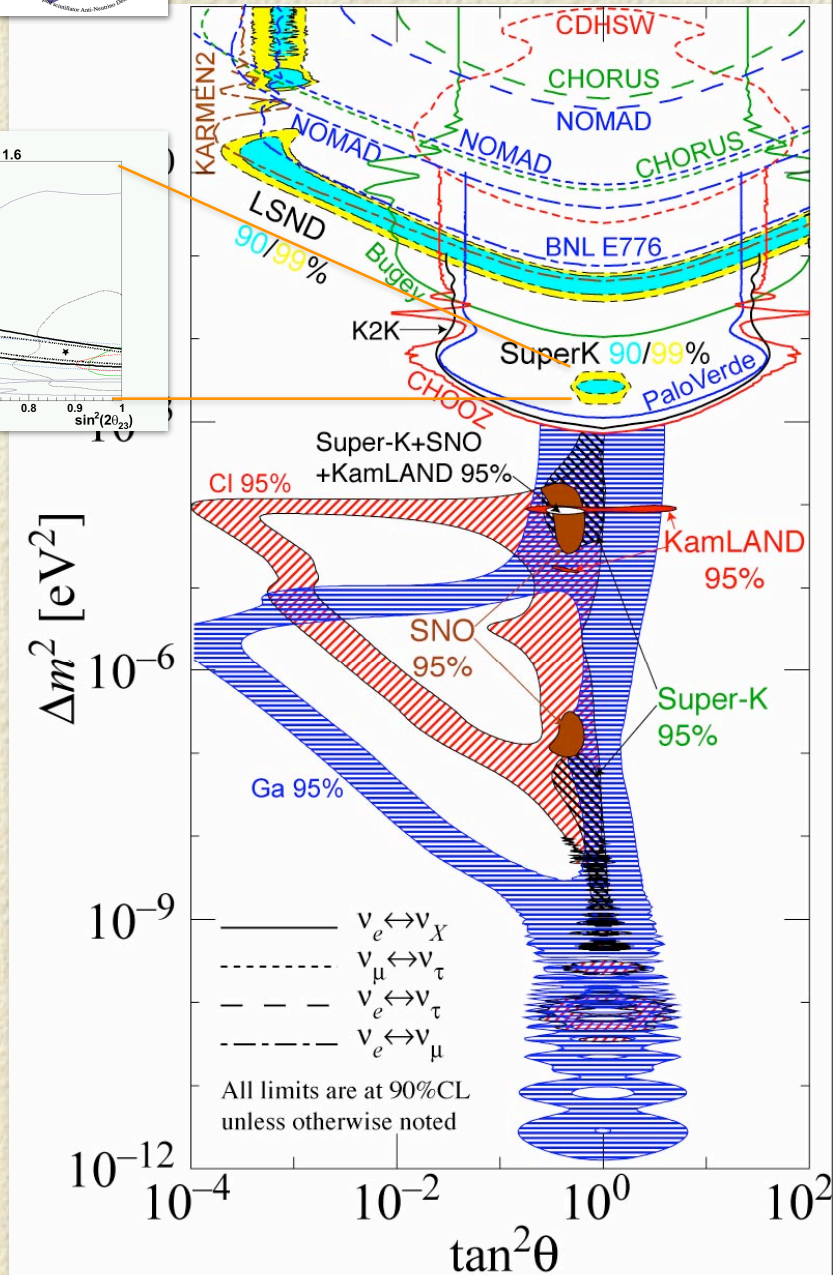
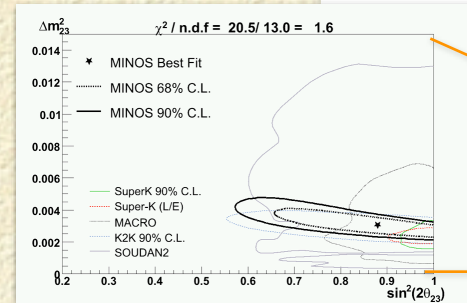
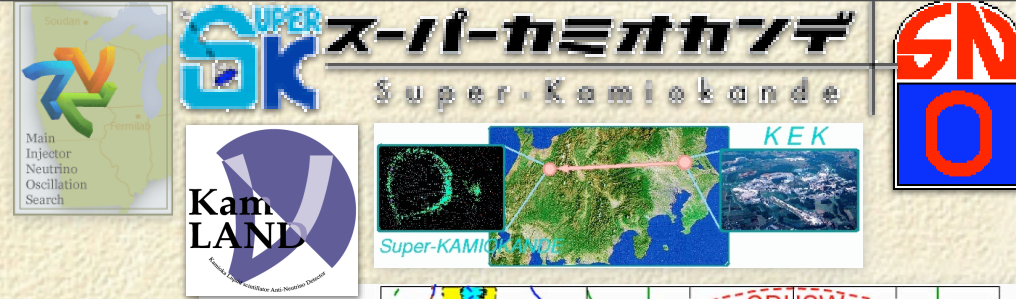
Physics Motivations for DUSEL: Neutrinos

- Neutrino Mass and Oscillations
- MNSP Matrix Elements
 - θ_{13} - size of angle
 - θ_{12} - unitarity of matrix
 - Mass hierarchy
- Sterile Neutrinos?
- CP Violation
- Neutrino Nature
(Dirac or Majorana)



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Physics Motivations for DUSEL: Neutrinos

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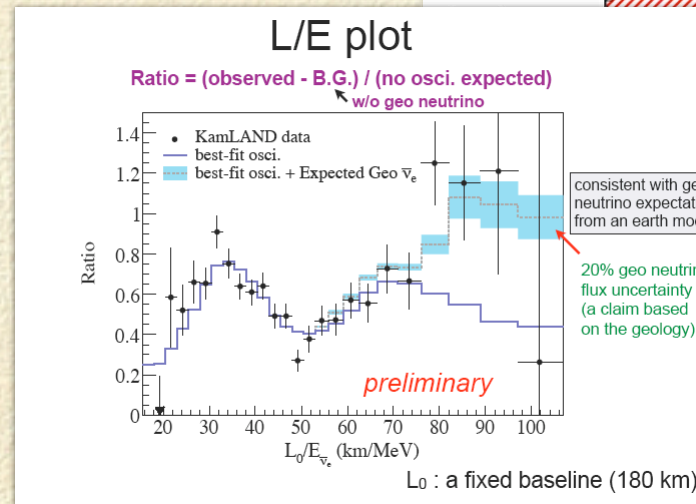
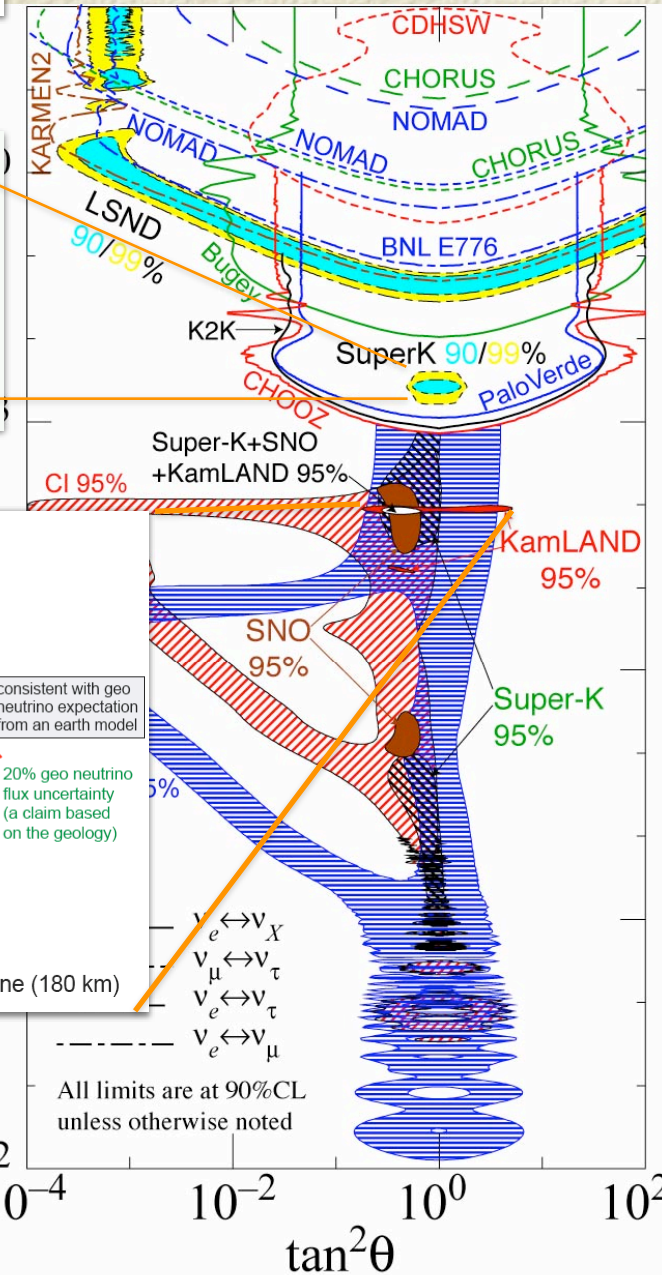
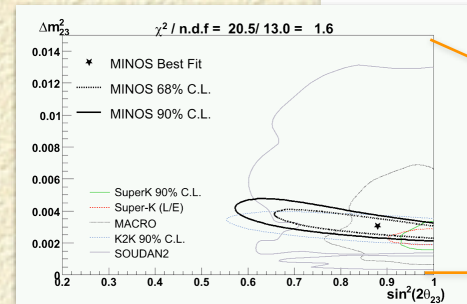
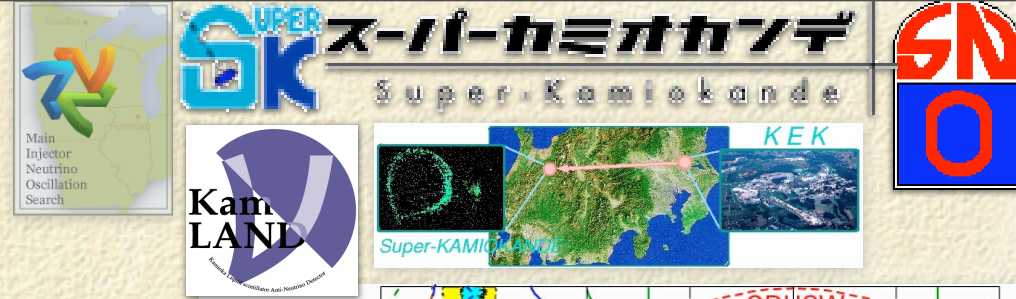
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Physics Motivations for DUSEL: Neutrinos

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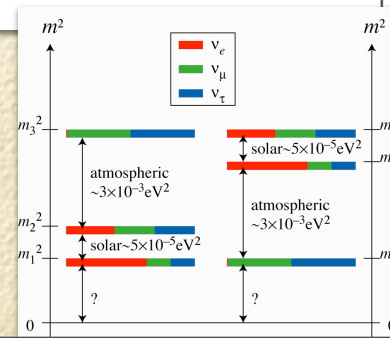
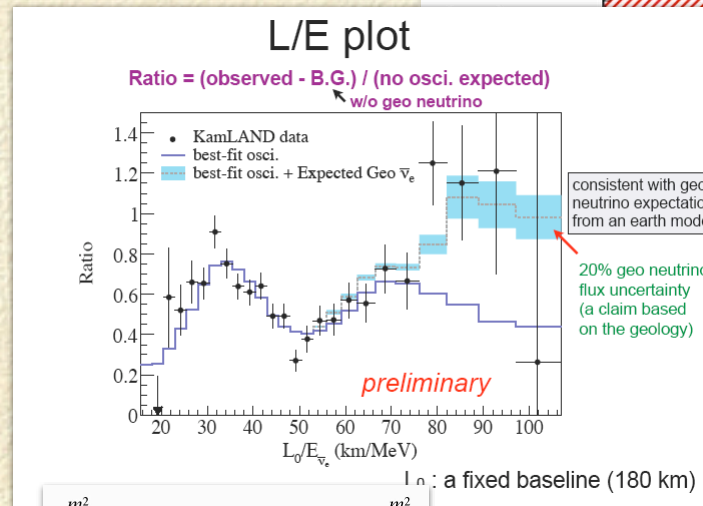
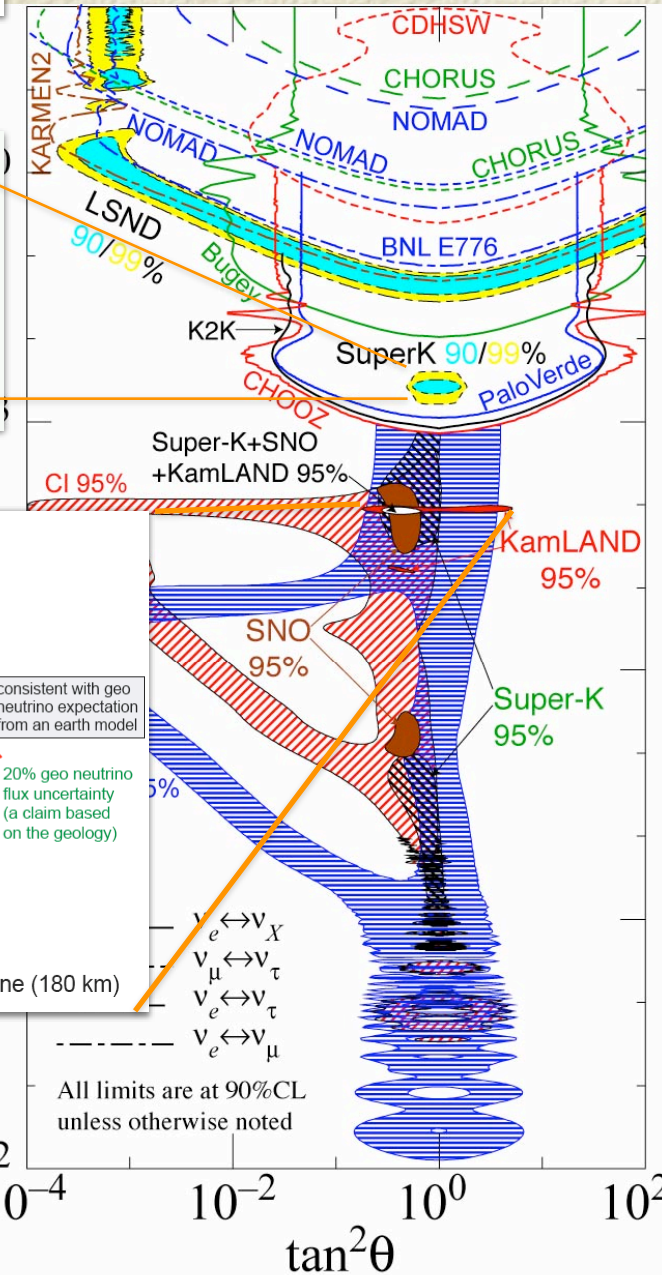
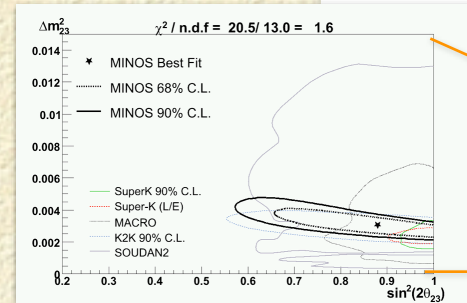
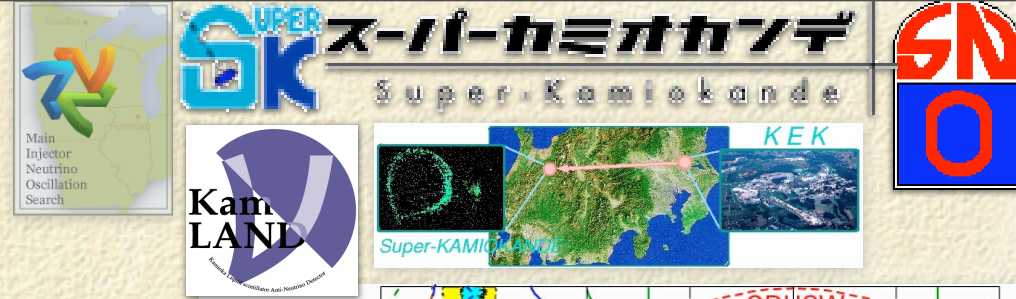
- MNSP Matrix Elements

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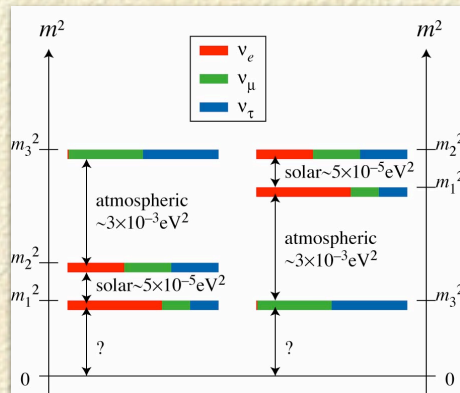


Physics Motivations: Long Baseline Neutrinos

Chooz
Double Chooz
Daya Bay

SNO
KamLAND
SuperK
BOREXINO

Super-K
MINOS
K2K
T2K



The Mixing Matrix

$$U = \begin{matrix} \text{Atmospheric} \\ \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \end{matrix} \times \begin{matrix} \text{Cross-Mixing} \\ \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \end{matrix} \times \begin{matrix} \text{Solar} \\ \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} \end{matrix}$$

$$\times \begin{bmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$c_{ij} \equiv \cos \theta_{ij}$$

$$s_{ij} \equiv \sin \theta_{ij}$$

$$\theta_{12} \approx \theta_{\text{sol}} \approx 35^\circ, \quad \theta_{23} \approx \theta_{\text{atm}} \approx 37-53^\circ, \quad \theta_{13} \lesssim 10^\circ$$

Majorana ~~CP~~
phases

δ would lead to $P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta) \neq P(\nu_\alpha \rightarrow \nu_\beta)$. ~~CP~~

But note the crucial role of $s_{13} \equiv \sin \theta_{13}$.

Adapted from Boris Kayser

Physics Motivations: Long Baseline Neutrinos

Accelerator ($\bar{\nu}$) Oscillation Probabilities

With $\alpha \equiv \Delta m_{21}^2 / \Delta m_{31}^2$, $\Delta \equiv \frac{\Delta m_{31}^2 L}{4E}$, and $x \equiv \frac{2\sqrt{2}G_F N_e E}{\Delta m_{31}^2}$ —

$$P[\nu_\mu \rightarrow \nu_e] \equiv \sin^2 2\theta_{13} T_1 - \alpha \sin 2\theta_{13} T_2 + \alpha \sin 2\theta_{13} T_3 + \alpha^2 T_4 ;$$

$$T_1 = \sin^2 \theta_{23} \frac{\sin^2[(1-x)\Delta]}{(1-x)^2}, \quad T_2 = \sin \delta \sin 2\theta_{12} \sin 2\theta_{23} \sin \Delta \frac{\sin(x\Delta)}{x} \frac{\sin[(1-x)\Delta]}{(1-x)},$$

$$T_3 = \cos \delta \sin 2\theta_{12} \sin 2\theta_{23} \cos \Delta \frac{\sin(x\Delta)}{x} \frac{\sin[(1-x)\Delta]}{(1-x)}, \quad T_4 = \cos^2 \theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(x\Delta)}{x^2}$$

$$P[\bar{\nu}_\mu \rightarrow \bar{\nu}_e] = P[\nu_\mu \rightarrow \nu_e] \text{ with } \delta \rightarrow -\delta \text{ and } x \rightarrow -x.$$

(Cervera *et al.*, Freund, Akhmedov *et al.*)

Physics Motivations: Long Baseline Neutrinos

Mixing of 3 ν s is complex, but can be done rigorously

Accelerator ($\bar{\nu}$) Oscillation Probabilities

With $\alpha \equiv \Delta m_{21}^2 / \Delta m_{31}^2$, $\Delta \equiv \frac{\Delta m_{31}^2 L}{4E}$, and $x \equiv \frac{2\sqrt{2}G_F N_e E}{\Delta m_{31}^2}$ —

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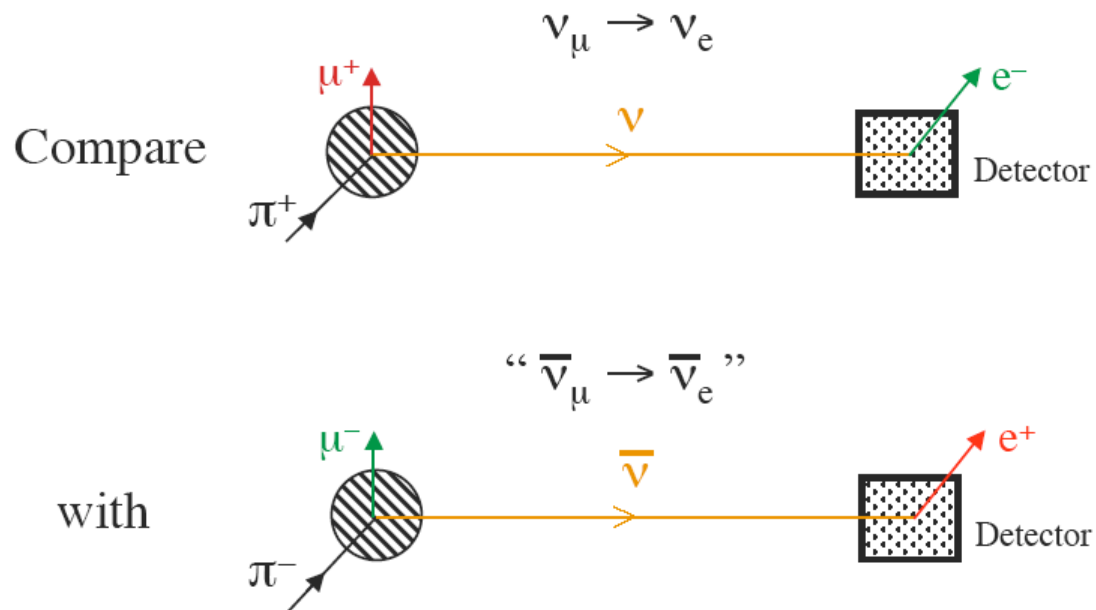
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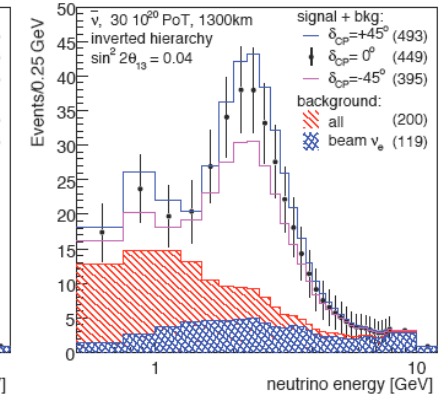
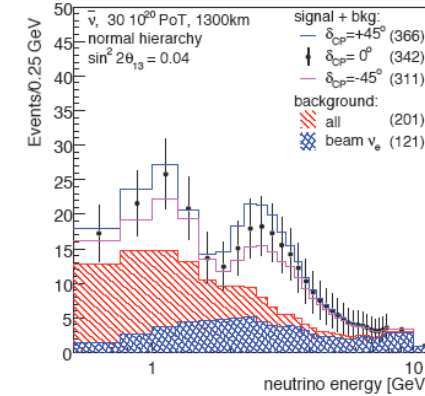
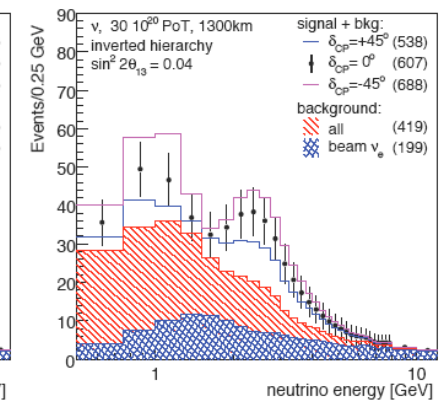
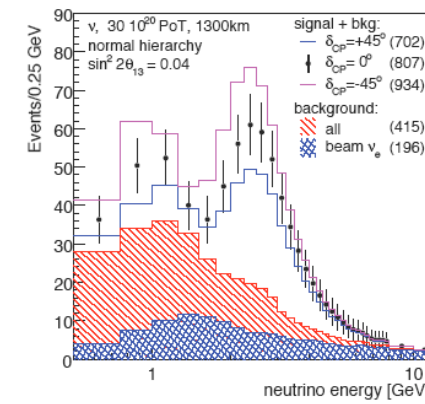
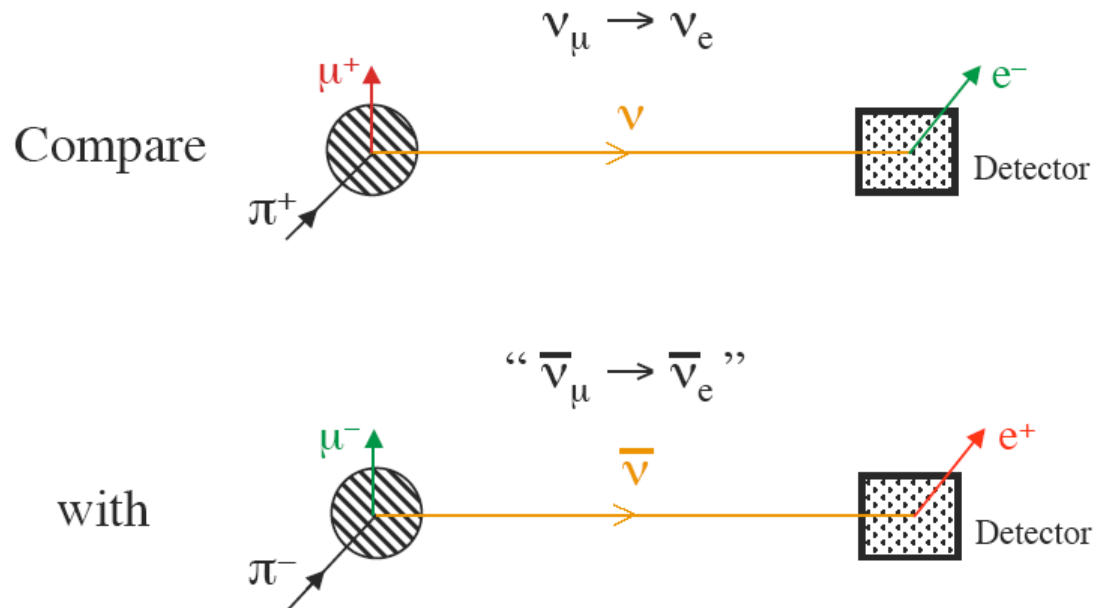
Physics Motivations: Long Baseline Neutrinos

CP Violation
Experiment: as
simple as...



Physics Motivations: Long Baseline Neutrinos

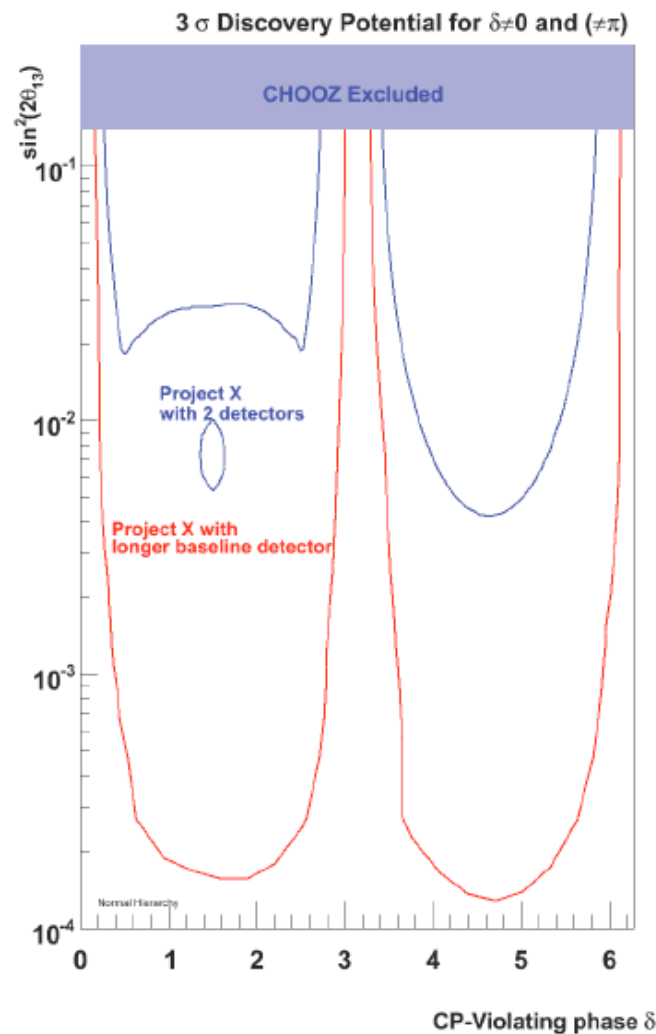
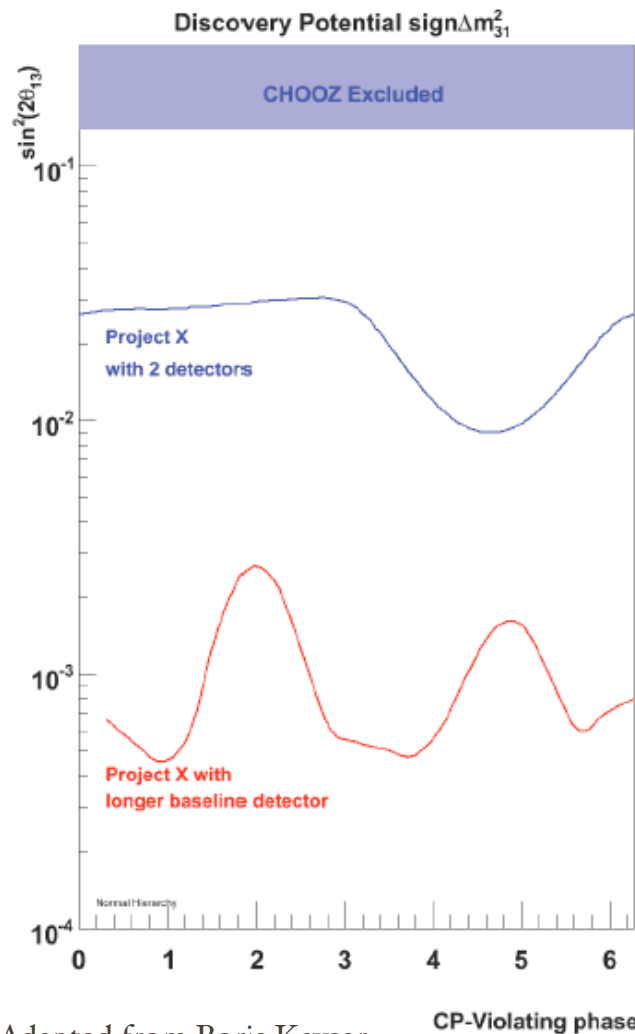
CP Violation Experiment: as simple as...



adapted Milind
Diwan

Physics Motivations: Long Baseline Neutrinos

Mass Ordering and \overline{CP} Reach of Project X



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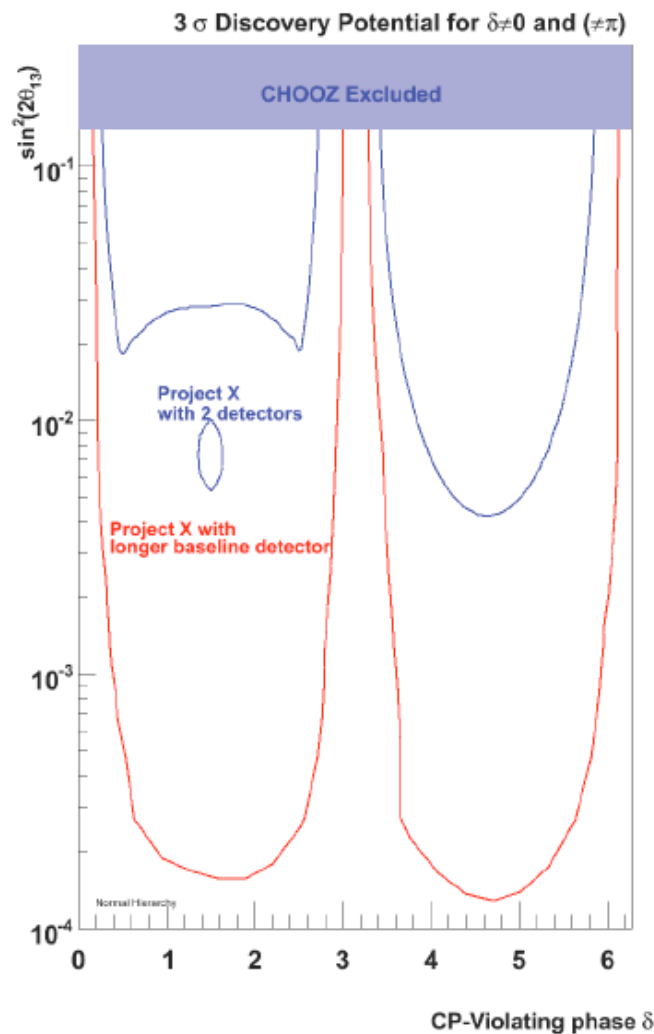
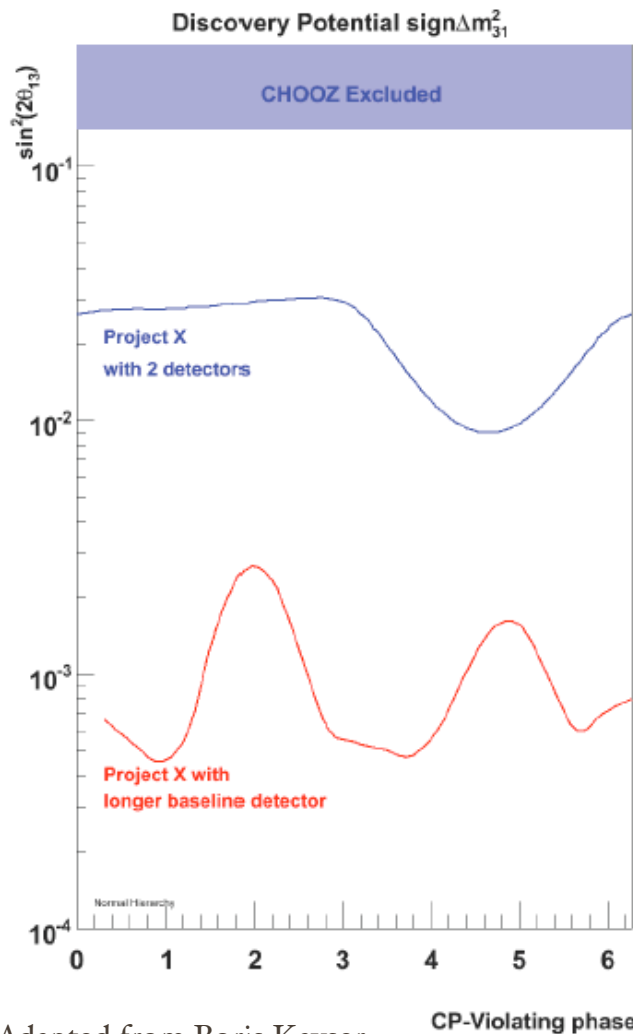
Adapted from Boris Kayser

CP-Violating phase δ

CP-Violating phase δ

Physics Motivations: Long Baseline Neutrinos

Mass Ordering and CP Reach of Project X



Requires Large
Detectors, Modest
Depths (100 to
1000 ft) and Long
Distances from ν
Sources
(> 1000 km)

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Physics Motivations for DUSEL: Nucleon Decay

Nonzero Baryon Number and assumptions of
 $B=0$ at $T=0$ imply proton decay

In the framework of GUTs

M_p = proton mass

M_U = Unification Mass Scale

$a_U \sim 1/30$

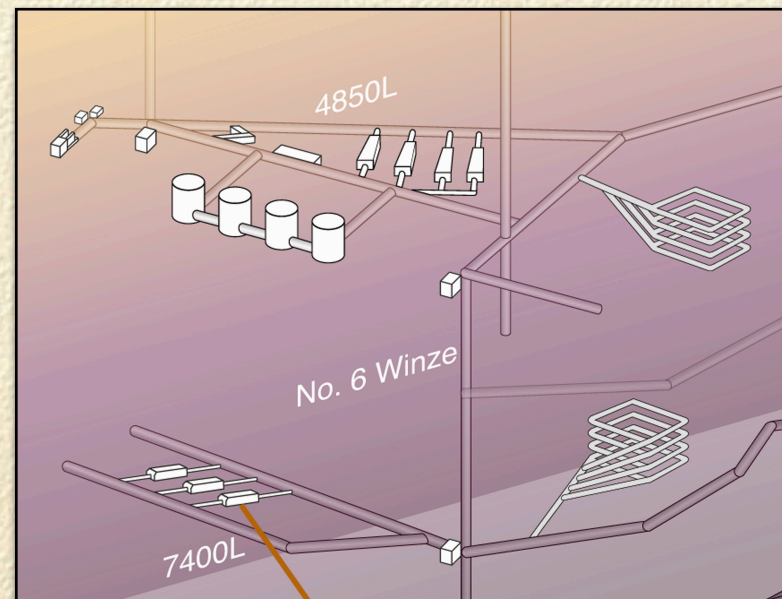
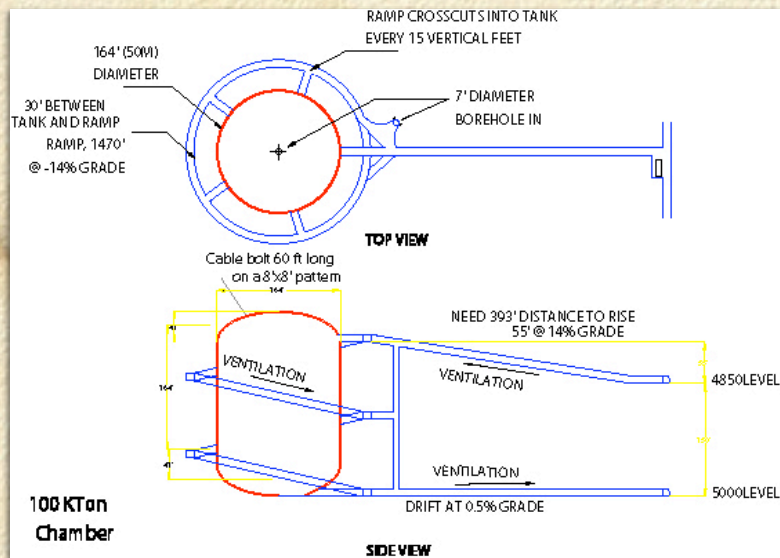
$$\frac{1}{\tau_p} = a_U^2 \frac{M_p^5}{M_U^4}$$

Therefore, $\tau_p \sim 10^{36}$ years (age of the universe
is few 10^{10} years)

Physics Motivations: Nucleon Decay

Same detectors used for nucleon decay experiments as in Long Baseline Neutrinos experiments:

~ 500kT detectors to approach $\tau \sim 10^{36}$ y

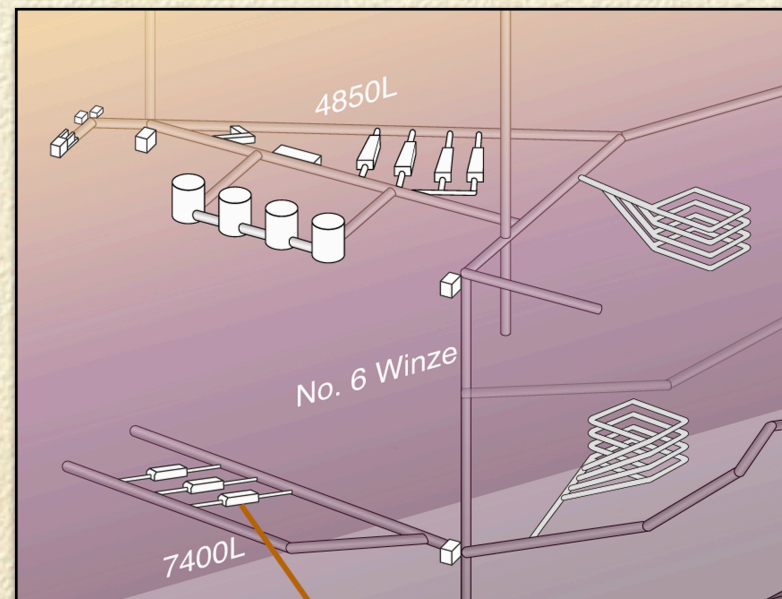
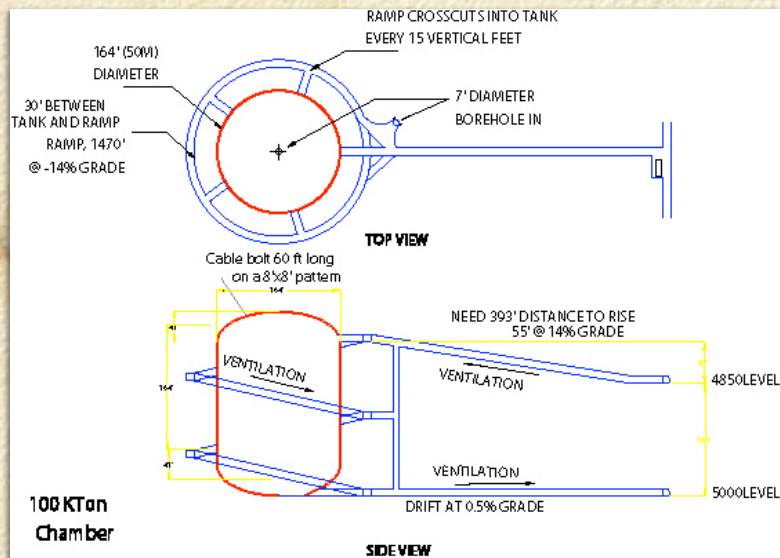


Physics Motivations: Nucleon Decay

Same detectors used for nucleon decay experiments as in Long Baseline Neutrinos experiments:

$\sim 500\text{kT}$ detectors to approach $\tau \sim 10^{36} \text{ y}$

Requires Very Large Detectors, Modest Depths ($\sim 5000 \text{ ft.}$), Stable and Long-term Excavations



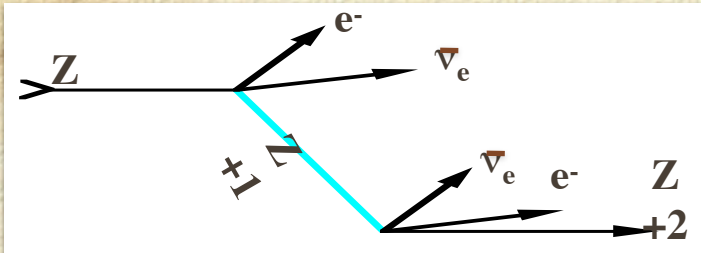
Physics Motivations: Neutrinos - Neutrinoless Double Beta Decay

- Oscillation experiments indicate ν s are massive, set relative mass scale, and minimum absolute mass
- β decay + cosmology set maximum for absolute mass
- One ν in the mass range: $45 \text{ meV} < m_\nu < 2200 \text{ meV}$
- $0\nu\beta\beta$ experiments may determine the absolute mass scale and only way to establish if neutrinos are Dirac or Majorana (if neutrino is its own antiparticle)
- $0\nu\beta\beta$ may establish mass hierarchy (order of ν s)
- Even null results are now interesting and useful

Physics Motivations: Neutrinos

- Neutrinoless Double Beta Decay

$2\nu\beta\beta$

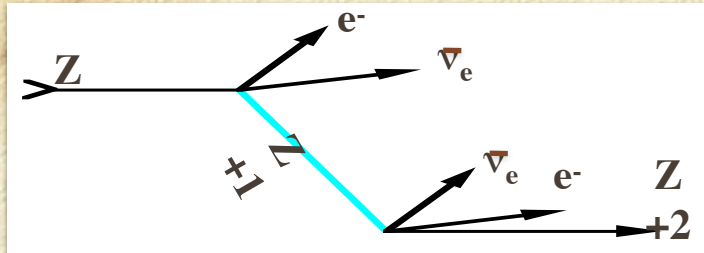


$$2n \Rightarrow 2p + 2e^- + 2\bar{\nu}_e$$

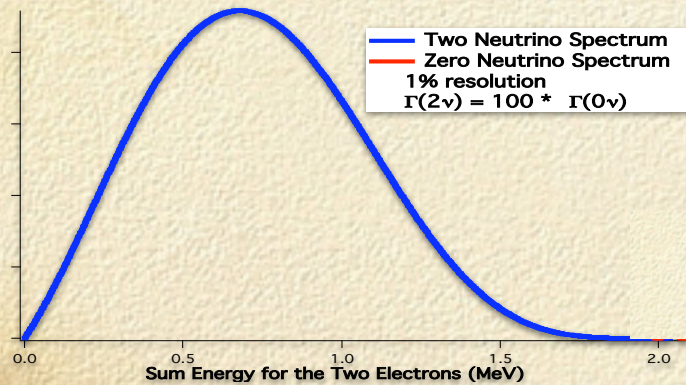
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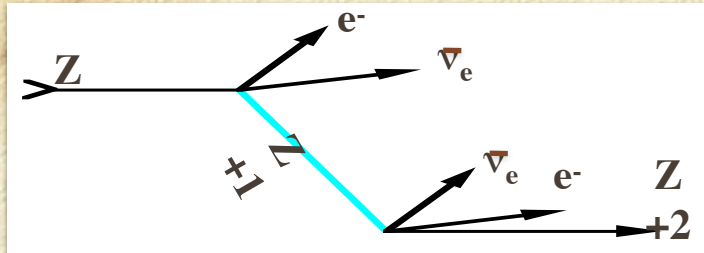
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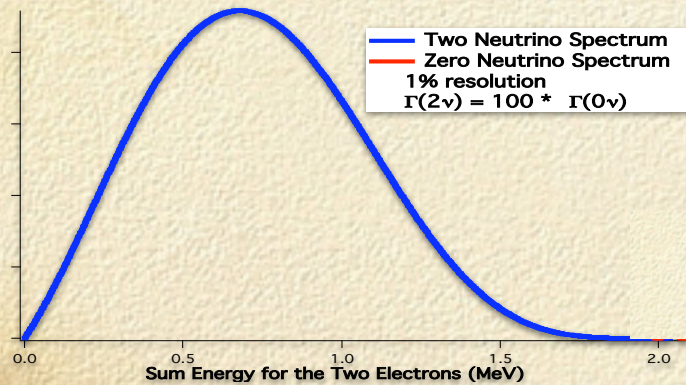
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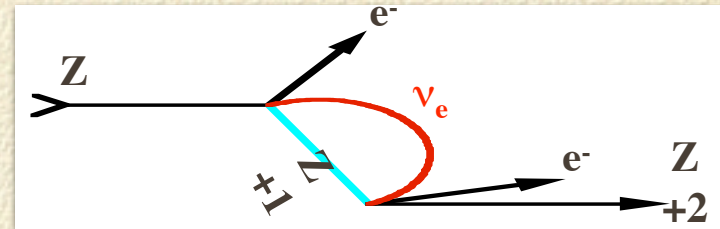
$2\nu\beta\beta$



$$2n \Rightarrow 2p + 2e^- + 2\bar{\nu}_e$$



$0\nu\beta\beta$



$$n \Rightarrow p + e^- + \bar{\nu}_e$$

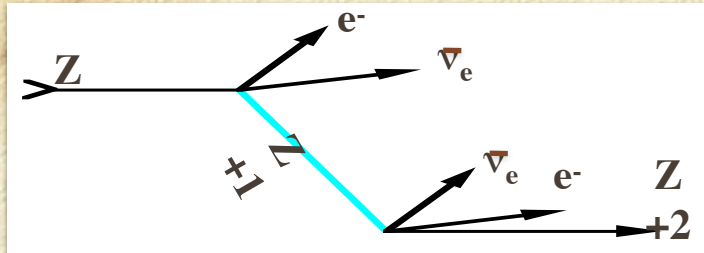
(RH $\bar{\nu}_e$) (LH ν_e)

$$\nu_e + n \Rightarrow p + e^-$$

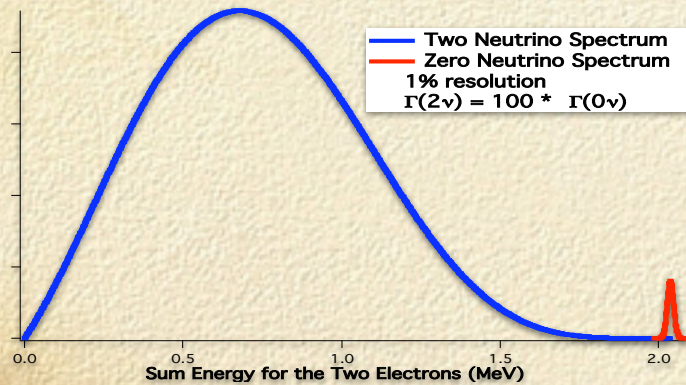
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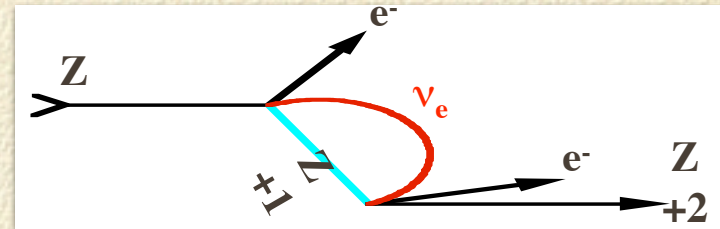
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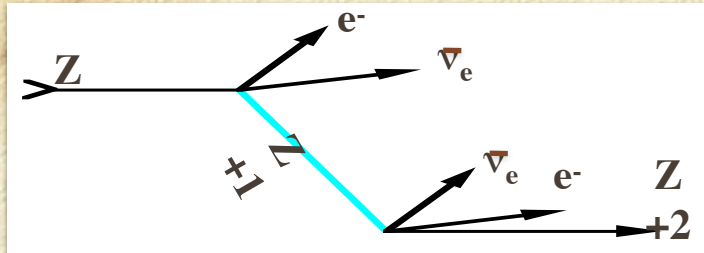
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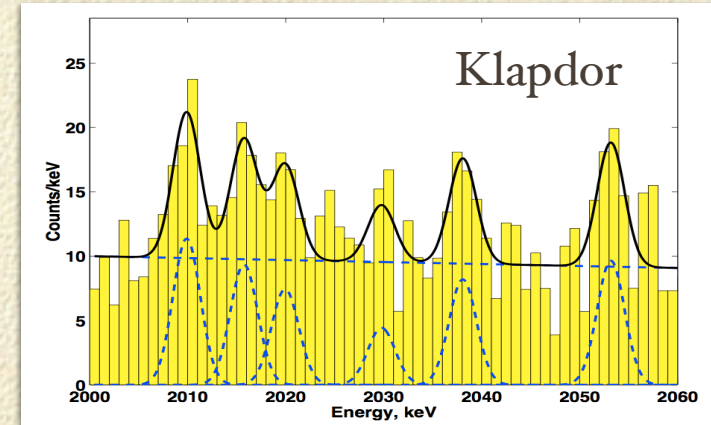
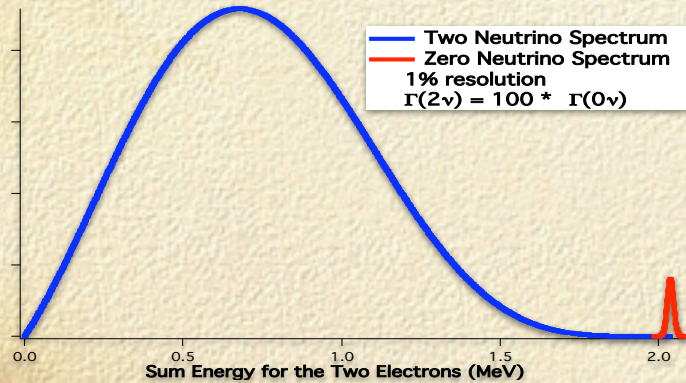
Physics Motivations: Neutrinos

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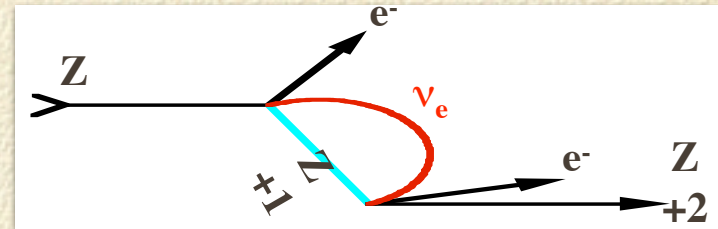
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$$2n \Rightarrow 2p + 2e^- + 2\bar{\nu}_e$$



$0\nu\beta\beta$



$$n \Rightarrow p + e^- + \bar{\nu}_e$$

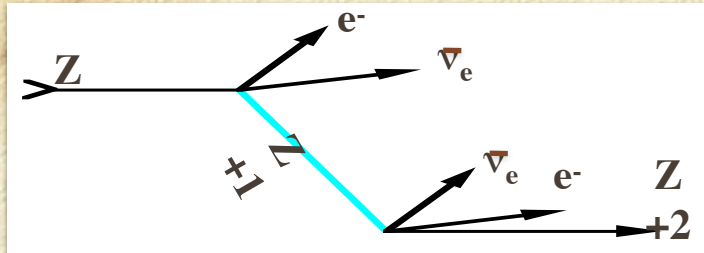
$(\text{RH } \bar{\nu}_e) \quad (\text{LH } \nu_e)$

$$\nu_e + n \Rightarrow p + e^-$$

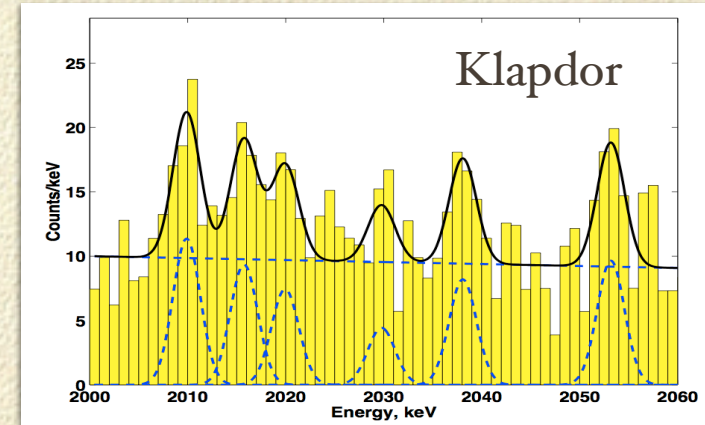
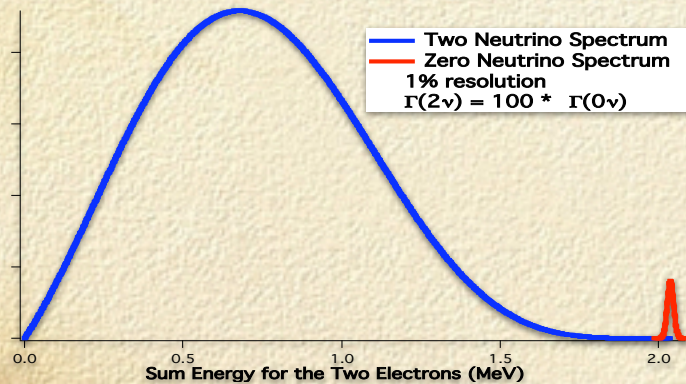
Physics Motivations: Neutrinos

- Neutrinoless Double Beta Decay

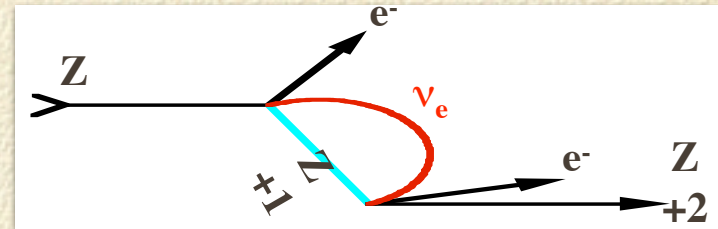
$2\nu\beta\beta$



$$2n \Rightarrow 2p + 2e^- + 2\bar{\nu}_e$$



$0\nu\beta\beta$



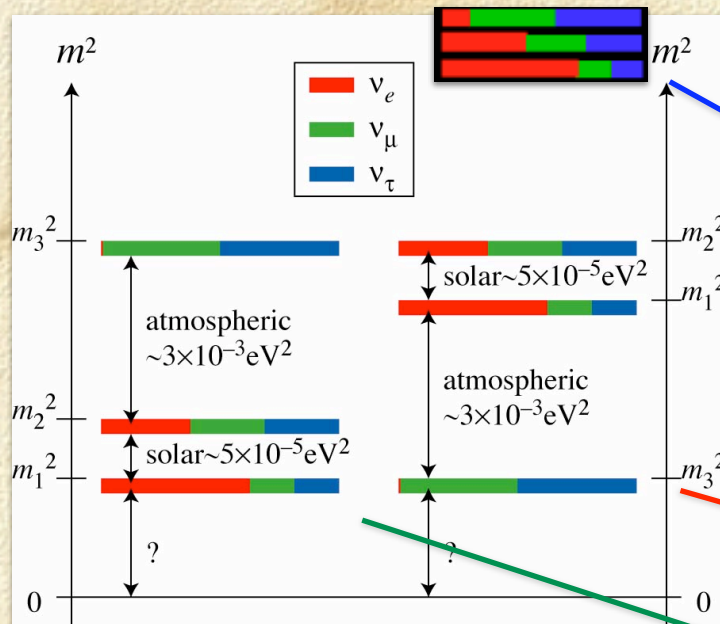
$$n \Rightarrow p + e^- + \bar{\nu}_e$$

(RH $\bar{\nu}_e$) (LH ν_e)

$$\nu_e + n \Rightarrow p + e^-$$

$$[T_{I/2}^{0\nu}]^{-1} = G^{0\nu}(E_0, Z) |\langle m_\nu \rangle|^2 \quad |M_F^{0\nu} - (g_A/g_V)^2 M_{GT}^{0\nu}|^2$$

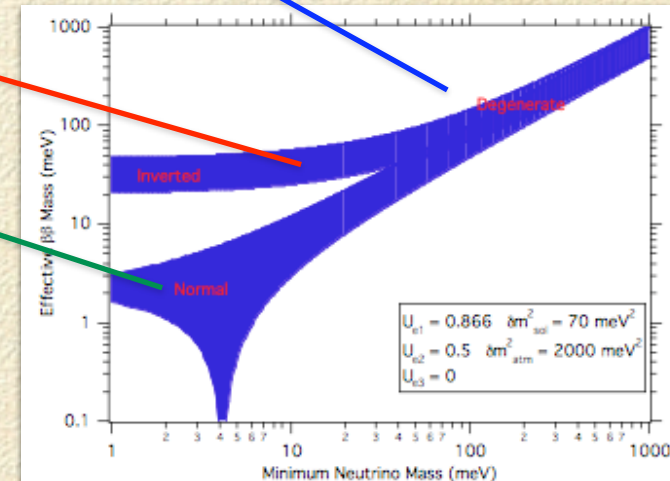
Physics Motivations: Neutrinos- Neutrinoless Double Beta Decay



Degenerate
Mass:
 $\sim 10 - 100 \text{ kg}$

Inverted
Hierarchy:
 $100 - 1000 \text{ kg}$

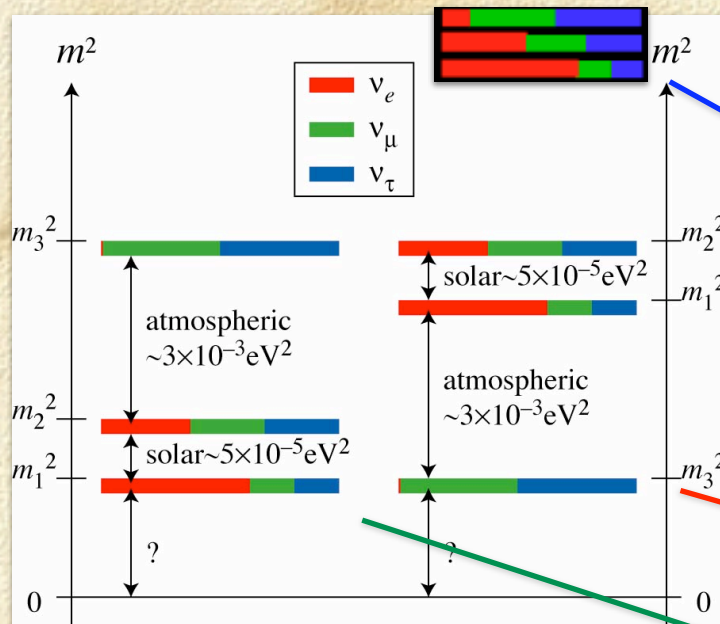
Normal
Hierarchy:
 $1 - 10 \text{ T}$



$$[T^{\text{ov}}_{I/2}]^{-I} = G^{\text{ov}}(E_o, Z) |\langle m_\nu \rangle|^2 |M^{\text{ov}}_F - (g_A/g_V)^2 M^{\text{ov}}_{GT}|^2$$

Physics Motivations: Neutrinos- Neutrinoless Double Beta Decay

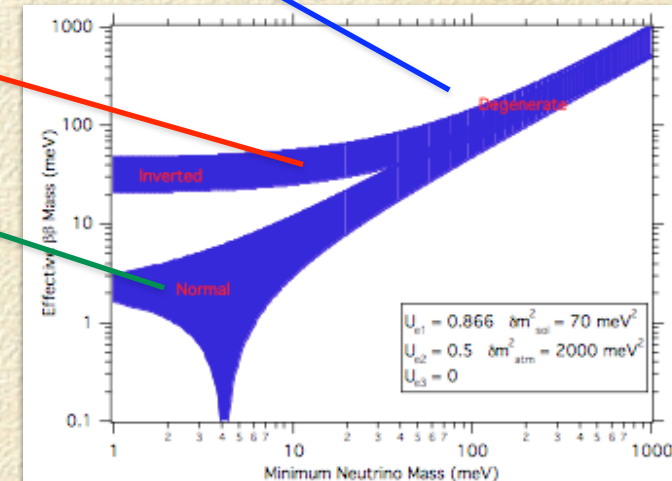
Requires Shielding
(great depth ~ 7400
ft.), Experimental
Support, Access,
Stability,
Environmental
Control



Degenerate
Mass:
 $\sim 10 - 100 \text{ kg}$

Inverted
Hierarchy:
 $100 - 1000 \text{ kg}$

Normal
Hierarchy:
 $1 - 10 \text{ T}$



$$[T^{\text{ov}}_{I/2}]^{-1} = G^{\text{ov}}(E_o, Z) |\langle m_\nu \rangle|^2 |M^{\text{ov}}_F - (g_A/g_V)^2 M^{\text{ov}}_{GT}|^2$$

Physics Motivations for DUSEL: Dark Matter

• Compelling evidence for DM

- Spiral Galaxy Rotational Curves
- Galactic Cluster Velocities
- Gravitational Lensing
- “Great Attractor” evidence within Large Clusters
- CMBR Large Scale Structure

$$\Omega_C = 35\%$$

• Types of DM

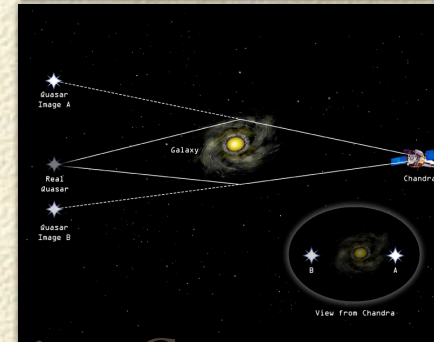
- Dark Baryons
 - Big Bang Nucleosynthesis
 - CMB Structure
 - Quasar Light Absorption by Gas Clouds
 - Counting Stars
- Exotic Dark Matter

$$\Omega_{\text{baryon}} = 4\%$$

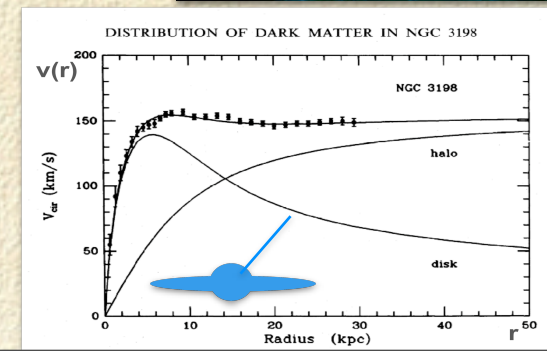
$$\Omega_{\text{baryon}} = 1.3\%$$

$$\Omega_{\text{exotic}} = \sim 30\%$$

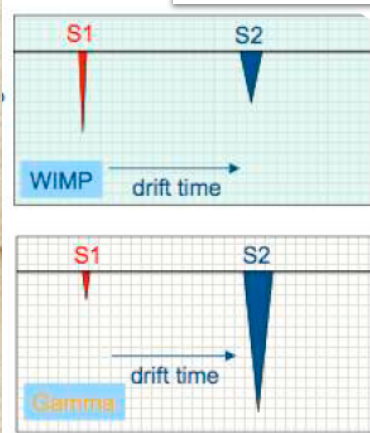
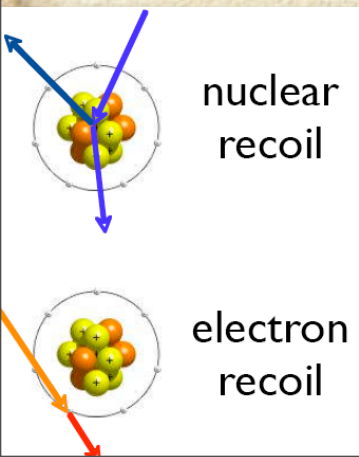
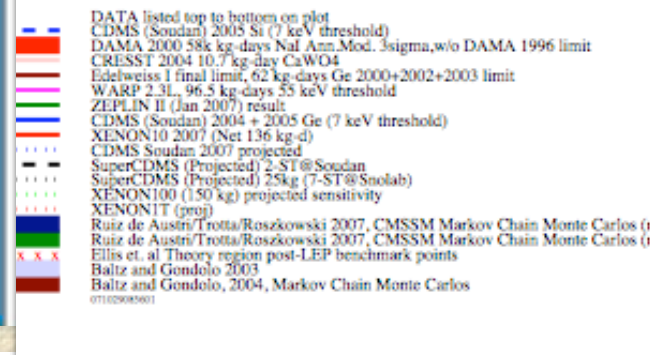
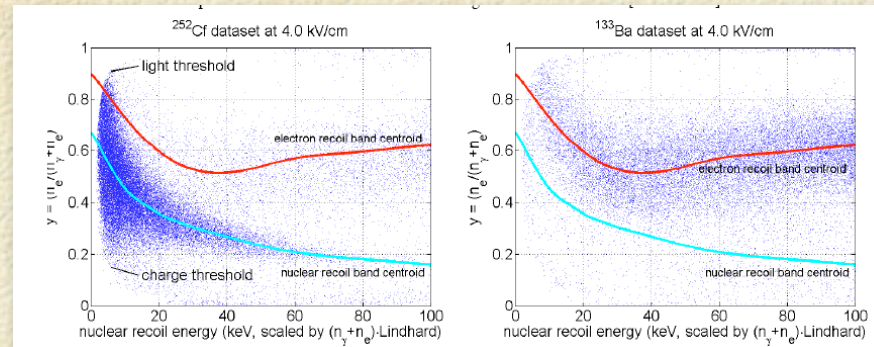
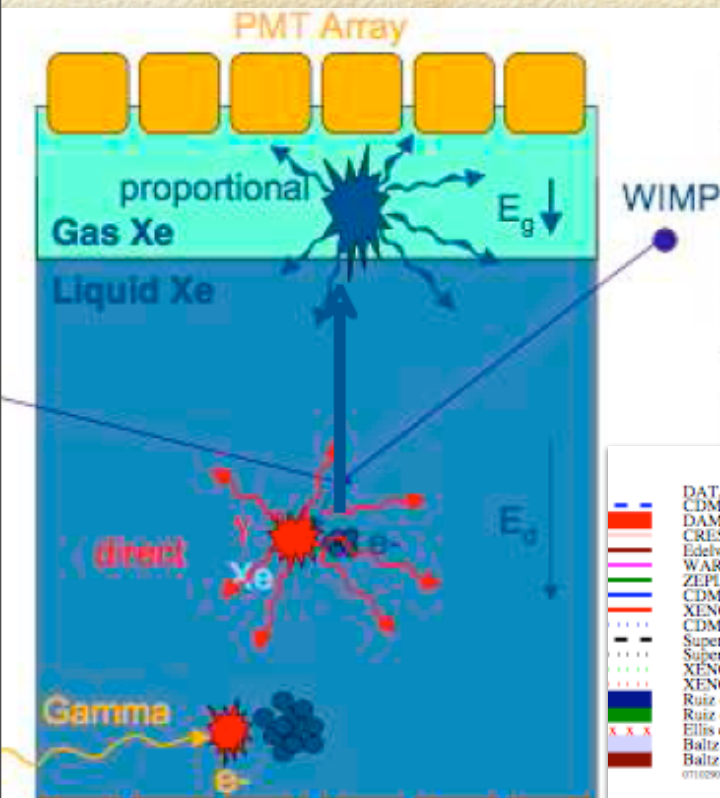
Gravitational Lensing



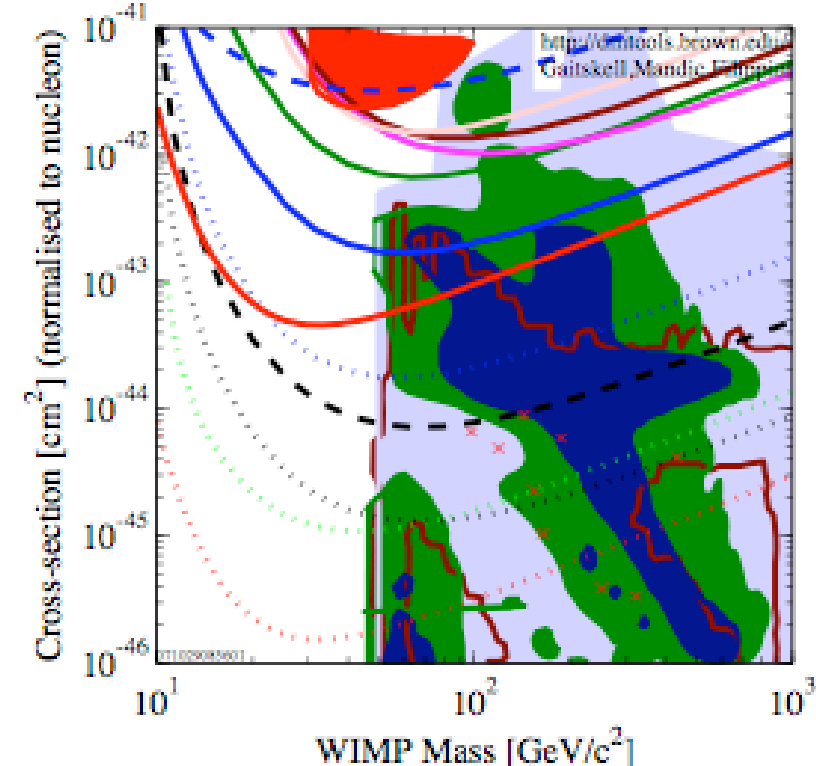
Galaxy Rotation Curves



Physics Motivations for DUSEL: Dark Matter

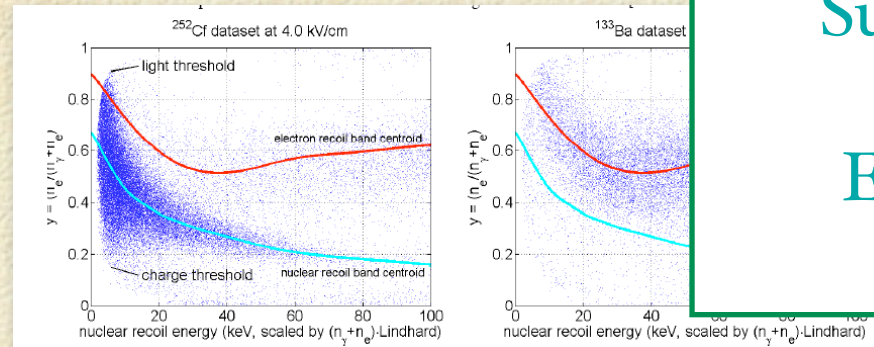
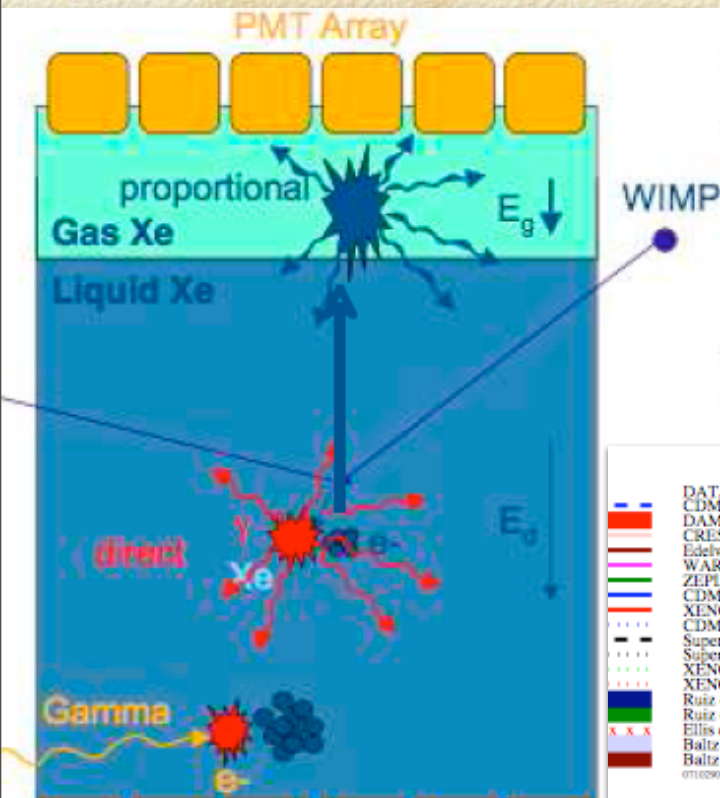


FOM:
1 ct/T/year

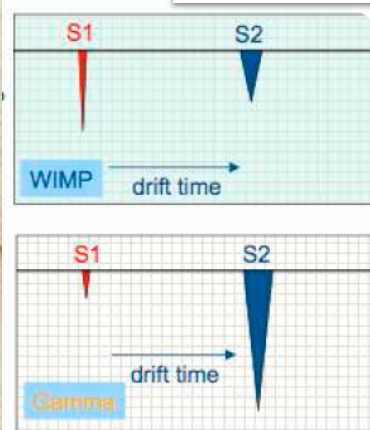
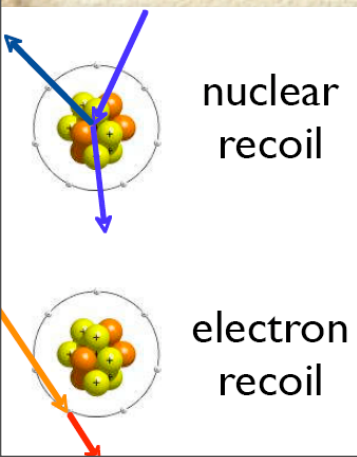


Physics Motivations for DUSEL: Dark Matter

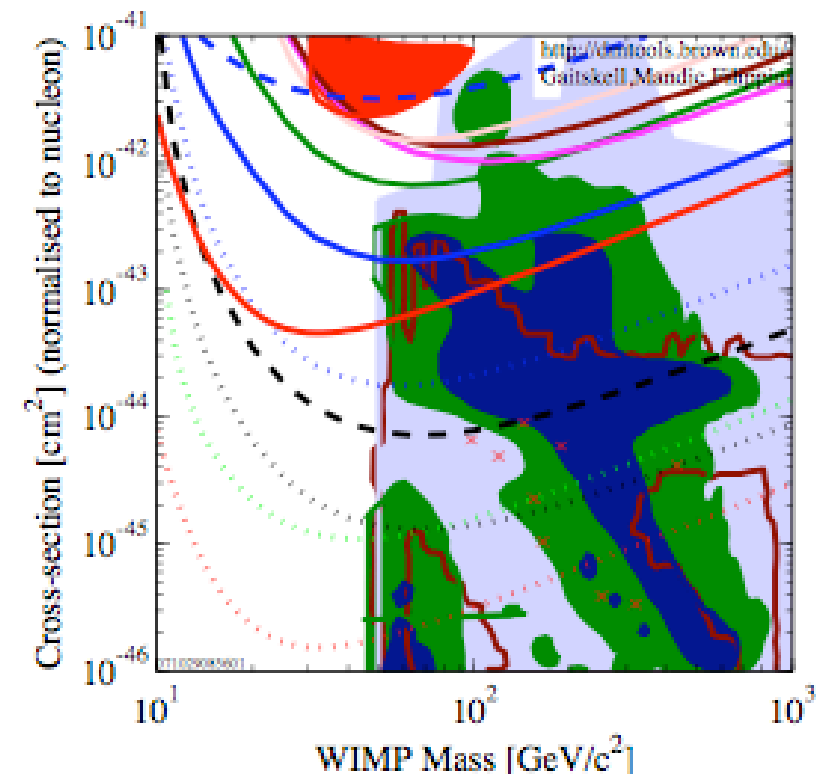
Requires Shielding
(great depth ~ 7400
ft.), Experimental
Support, Access,
Stability,
Environmental
Control



DATA listed top to bottom on plot
 CDMS (Soudan) 2005 Si (7 keV threshold)
 DAMA 2000 58kg kg-days NaI Ann.Mod. 3σ limit, w/o DAMA 1996 limit
 CRESST 2004 10.7 kg-day CaWO₄
 Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
 WARP 2.3L, 96.5 kg-days 55 keV threshold
 ZEPLIN II (Jan 2007) result
 CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
 XENON10 2007 (Net 136 kg-d)
 CDMS Soudan 2007 projected
 SuperCDMS (Projected) 2-ST @ Soudan
 SuperCDMS (Projected) 25kg (7-ST @ Snolab)
 XENON100 (150 kg) projected sensitivity
 XENONIT (proj)
 Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (i
 Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (i
 Ellis et. al Theory region post-LEP benchmark points
 Baltz and Gondolo 2003
 Baltz and Gondolo, 2004, Markov Chain Monte Carlos
 0711.0290v2

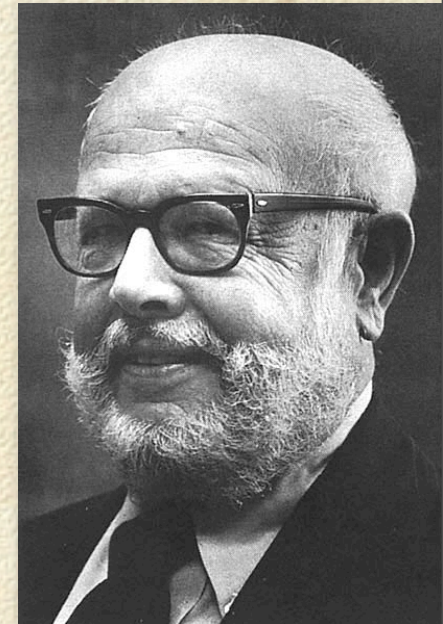
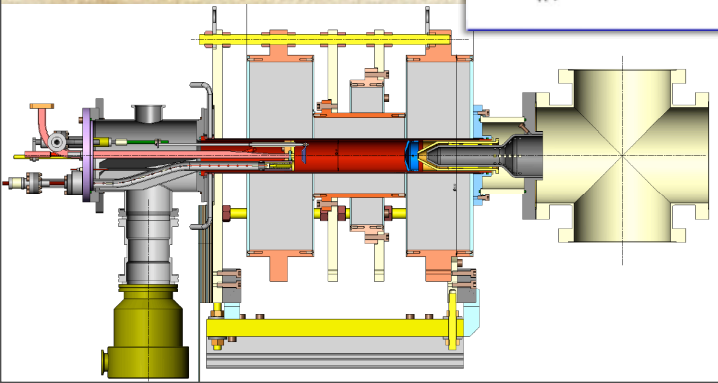
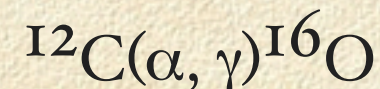
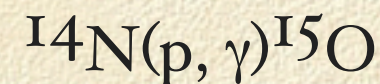
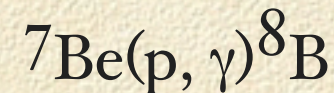
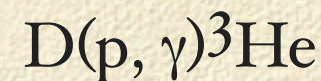
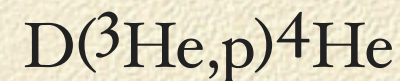
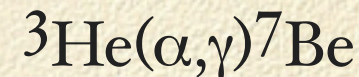
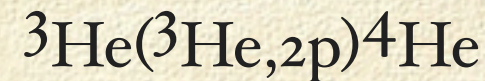
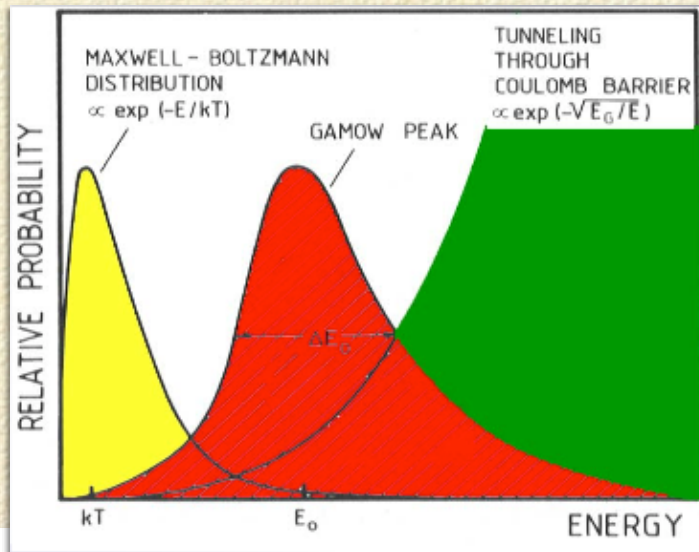


FOM:
1 ct/T/year



Physics Motivations for DUSEL: Nucleosynthesis

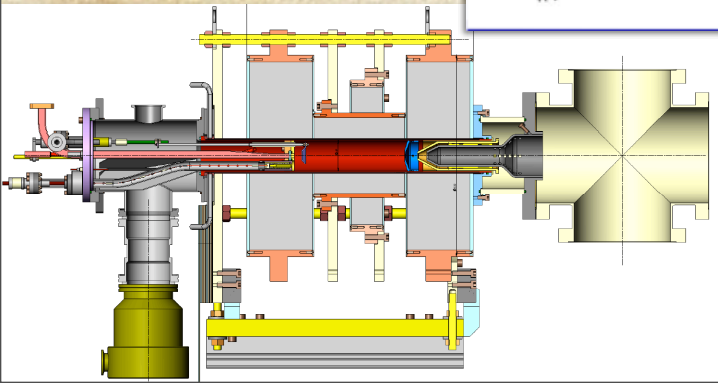
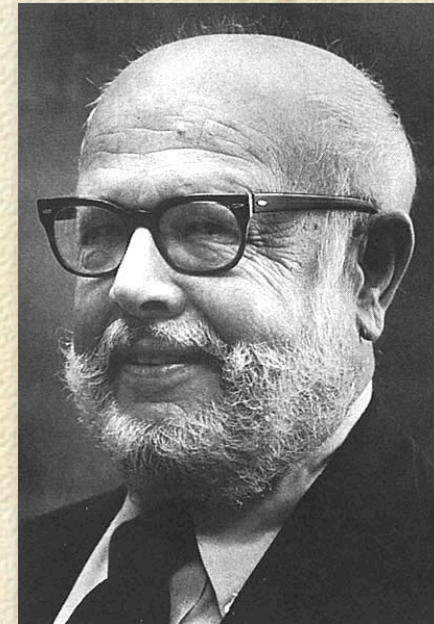
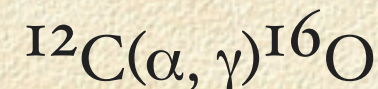
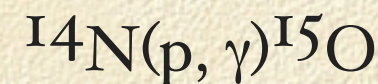
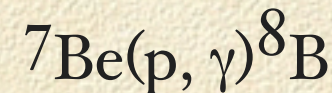
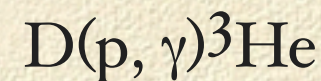
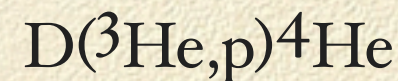
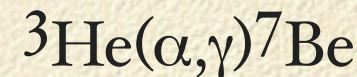
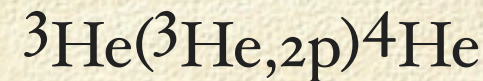
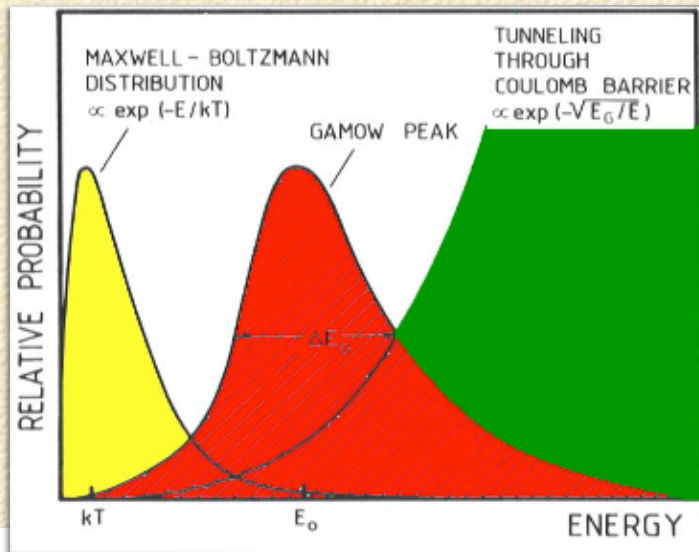
- $A > 60$ formation in Supernovae, ν interactions
- Sources of neutrons for s-, r- processes
- Details of Lower Mass Nucleosynthesis
- pp chain
- CNO



Physics Motivations for DUSEL: Nucleosynthesis

- $A > 60$ formation in Supernovae, ν interactions
- Sources of neutrons for s-, r- processes
- Details of Lower Mass Nucleosynthesis
- pp chain
- CNO

Requires
Moderate
Depth
(~ 5000 ft),
Underground
Accelerators,
EH&S



Motivations from Other Disciplines

- How do biology and geology interact to shape the world underground?
- How does subsurface microbial life evolve in isolation?
- Did life on earth originate beneath the surface?
- Is there life underground as we don't know it?
- What are the interactions among subsurface processes?
- Are underground resources of drinking water safe and secure?
- Can we reliably predict and control earthquakes?
- Can we make the earth “transparent” and observe underground processes in action?
- What are the mechanical properties of rock?
- What lies between the boreholes?
- How does rock respond to human activity?
- How does water flow deep underground?
- How can technology lead to a safer underground?

Initial Suite of Physics Experiments

- Based upon the November town meeting:
 - neutrinoless double beta decay
 - dark matter searches
 - nuclear astrophysics
 - beginning of a phased development of long baseline neutrinos and proton decay
(~ begin with 100kt?)

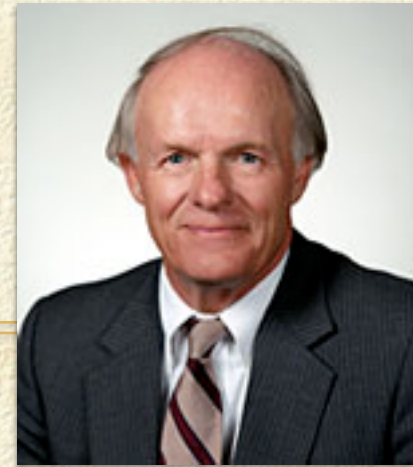
Workshops in South Dakota

- 21-28 April 2008
- Homestake is arranging to host a series of comprehensive workshops at Lead, SD
- Details to be forthcoming, but along the lines of our previous workshops:
 - physics
 - biology
 - earth science & engineering
 - common facilities and cross-cutting research
 - education and public outreach
- Disciplines/experiments likely to establish additional workshops and meetings

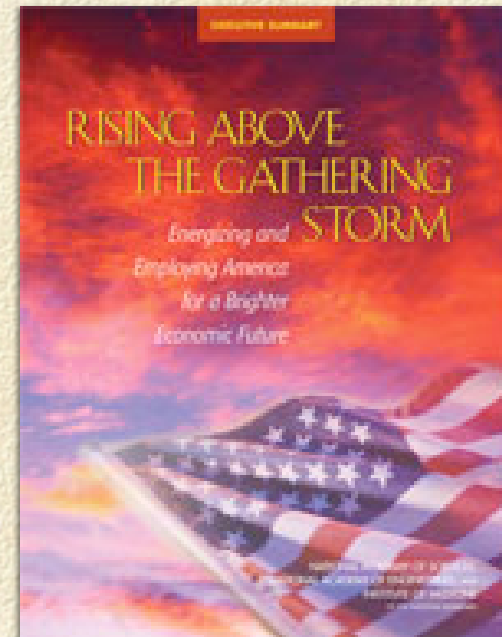
Center for Underground Science

- ❑ To facilitate interactions with the Facility we are developing a “Center”
 - ❑ host “sabbatical leave” & short-term visits
 - ❑ develop collaborations
 - ❑ develop experimental plans
 - ❑ work with engineers to develop facility requirements and criteria for DUSEL plans
- ❑ To begin ~ January 2008, coordinate by topics
- ❑ Arranging sponsorship among various sources: SLAC very interested, active discussions with FNAL and other laboratories

Sanford Gift: \$70M



- Gift 1: \$35M to be made in two installments
 - Gift 1 Part 1: \$15M by December 2007
 - Gift 1 Part 2: \$20M by December 2008
- For 4850L laboratory and infrastructure: i.e. lifts, access, custom space, operations, surface space, radon-reduced air, ...
- Gift 2: \$20M
 - \$20M by December 2009
 - Establish the Sanford Science Center (E&O)
- Gift 3: \$15M
 - between January 2010 - December 2012
 - For going deep, 7400 level lab





Triggers for the Gift

□ Gift 1 - \$35M 2007 - 2008

- NSF selects Homestake as sole candidate site for DUSEL
- Laboratory is named Sanford Underground Science and Engineering Laboratory (SUSEL-Homestake)
- SDSTA spends their \$ (rehabilitation and re-entry)
- Significant scientific demand (defining users of EIP)
 - measured by MOUs ~ \$10M



Triggers for the Gift

□ Gift 2 - \$20M 2009

- Gift 1 triggers satisfied
- naming rights - **Sanford Science Education Center**
- SDSTA develops “business plan” and spends their \$ on center

□ Creates ~50,000 ft² education & outreach center

□ Gift 3 - \$15M 2010-2012

- Gift 1 and 2 conditions satisfied
- National funding for the laboratory (NSF, DOE, etc.) to the tune of \$15M
- SDSTA spend their \$